Cost Study of Alternatives Presented in the Draft Environmental Impact Statement for the Treatment and Management of Sodium-Bonded Spent Nuclear Fuel

August 1999

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ACRONYMS

ANL-W	Argonne National Laboratory-West
DOE	U.S. Department of Energy
EBR-II	Experimental Breeder Reactor-II
EIS	Environmental Impact Statement
FR	Federal Register
FTE	Full-Time Equivalent
GMODS	Glass Material Oxidation and Dissolution System
INEEL	Idaho National Engineering and Environmental Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
MEDEC	Melt, Drain, Evacuate, and Calcine
NEPA	National Environmental Policy Act
NRC	U.S. Nuclear Regulatory Commission
PUREX	Plutonium-Uranium Extraction
SBSNF	Sodium-Bonded Spent Nuclear Fuel
SRS	Savannah River Site

Metric Conversion Chart

To Convert Into Metric			*To Convert From Metric*		
If You Know	**Multiply By**	**To Get**	**If You Know**	**Multiply By**	**To Get**
Length					
inches	2.54	centimeters	centimeters	0.3937	inches
feet	30.48	centimeters	centimeters	0.0328	feet
feet	0.3048	meters	meters	3.281	feet
yards	0.9144	meters	meters	1.0936	yards
miles	1.60934	kilometers	kilometers	0.6214	miles
Area					
square inches	6.4516	square centimeters	square centimeters	0.155	square inches
square feet	0.092903	square meters	square meters	10.7639	square feet
square yards	0.8361	square meters	square meters	1.196	square yards
acres	0.40469	hectares	hectares	2.471	acres
square miles	2.58999	square kilometers	square kilometers	0.3861	square miles
Volume					
fluid ounces	29.574	milliliters	milliliters	0.0338	fluid ounces
gallons	3.7854	liters	liters	0.26417	gallons
cubic feet	0.028317	cubic meters	cubic meters	35.315	cubic feet
cubic yards	0.76455	cubic meters	cubic meters	1.308	cubic yards
Weight					
ounces	28.3495	grams	grams	0.03527	ounces
pounds	0.4536	kilograms	kilograms	2.2046	pounds
short tons	0.90718	metric tons	metric tons	1.1023	short tons
Temperature					
Fahrenheit	Subtract 32, then multiply by 5/9ths	Celsius	Celsius	Multiply by 9/5ths, then add 32	Fahrenheit

Metric Prefixes

Prefix	***Symbol***	***Multiplication Factor***
exa-	E	1 000 000 000 000 000 000 = 10^{18}
peta-	P	1 000 000 000 000 000 = 10^{15}
tera-	T	1 000 000 000 000 = 10^{12}
giga-	G	1 000 000 000 = 10^{9}
mega-	M	1 000 000 = 10^{6}
kilo-	k	1 000 = 10^{3}
hecto-	h	100 = 10^{2}
deka-	da	10 = 10^{1}
deci-	d	0.1 = 10^{-1}
centi-	c	0.01 = 10^{-2}
milli-	m	0.001 = 10^{-3}
micro-	μ	0.000 001 = 10^{-6}
nano-	n	0.000 000 001 = 10^{-9}
pico-	p	0.000 000 000 001 = 10^{-12}
femto-	f	0.000 000 000 000 001 = 10^{-15}
atto-	a	0.000 000 000 000 000 001 = 10^{-18}

SUMMARY

The following is a summary of the results of a study conducted on the potential costs of treating and managing Department of Energy (DOE)-owned sodium-bonded spent nuclear fuel at Argonne National Laboratory-West (ANL-W) and the Savannah River Site (SRS). The alternatives for the proposed treatment and management of sodium-bonded spent nuclear fuel that were evaluated in the cost study are presented in the July 1999 *Draft Environmental Impact Statement for the Treatment and Management of Sodium-Bonded Spent Nuclear Fuel* (SBSNF Draft EIS). The cost study provides a relative comparison of the costs between the alternatives described in the SBSNF Draft EIS. The cost study goes beyond the scope of the environmental impact statement (EIS) to analyze program costs for the life-cycle treatment and management of the sodium-bonded spent nuclear fuel. It allows DOE to include consideration of estimated life-cycle costs in the decision-making process, and may form a base for initial planning toward ultimate disposition.

Costs of potential decisions typically are not evaluated in an EIS, but DOE recognizes that the financial implications of its future programs are important considerations for decision-making and has resolved to inform the public about those costs. The results of the cost study and public input received on the SBSNF Draft EIS are among the factors that DOE will consider when preparing the Record of Decision.

The costs evaluated in this cost study are associated with the six alternatives under the proposed action and a No Action Alternative that involves direct disposal and a deferred decision on the disposal of the spent nuclear fuel. Each alternative, with the exceptions of the No Action Alternative and Alternative 6, involves the electrometallurgical treatment of driver spent nuclear fuel. Differences in costs associated with Alternatives 1 through 6 are related to the methods proposed for treating blanket spent nuclear fuel. Various methods for the treatment and management of spent nuclear fuel are described in more detail in the SBSNF Draft EIS and Appendix A of this cost study. Alternatives for treating and managing sodium-bonded spent nuclear fuel that were evaluated in this cost study include:

- **No Action Alternative**—Direct disposal and a deferred decision on disposal options
- **Alternative 1**—Electrometallurgical treatment of driver and blanket spent nuclear fuel at ANL-W
- **Alternative 2**—Electrometallurgical treatment of driver spent nuclear fuel; sodium removal and package blanket spent nuclear fuel in high-integrity cans at ANL-W
- **Alternative 3**—Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and PUREX process blanket spent nuclear fuel at SRS
- **Alternative 4**—Electrometallurgical treatment of driver spent nuclear fuel and melt and dilute blanket spent nuclear fuel at ANL-W
- **Alternative 5**—Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and melt and dilute blanket spent nuclear fuel at SRS
- **Alternative 6**—Melt and dilute driver and blanket spent nuclear fuel at ANL-W

Table S-1 presents the total program costs of the No Action Alternative and the six other alternatives as net present values in year-2000 dollars, including contingencies and escalation. The net present value is the amount required to exactly cover program expenditures as they arise over the life of the program.

Table S–1 Cost Summary (in Millions of Dollars)

Alternative	*Net present value in year-2000 dollars (including contingencies and escalation)*
No Action Alternative: Direct disposal	**443**
Alternative 1: Electrometallurgical treatment of driver and blanket spent nuclear fuel at ANL-W	**604**
Alternative 2: Electrometallurgical treatment of driver spent nuclear fuel with sodium removal and package blanket spent nuclear fuel in high-integrity cans at ANL-W	**512**
Alternative 3: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and PUREX process blanket spent nuclear fuel at SRS	**545**
Alternative 4: Electrometallurgical treatment of driver spent nuclear fuel and melt and dilute blanket spent nuclear fuel at ANL-W	**686**
Alternative 5: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and melt and dilute blanket spent nuclear fuel at SRS	**686**
Alternative 6: Melt and dilute driver and blanket spent nuclear fuel at ANL-W	**753**

Although net present value costs are shown in Table S–1 to three significant figures, the relative merits of the alternatives should be judged cautiously on the basis of the absolute differences among these figures because:

1. It is uncertain whether each of the alternatives will be able to satisfy repository waste acceptance criteria.

2. The technical feasibility of the alternatives varies, and although the Table S–1 costs include contingencies, they do not reflect unquantifiable risks.

3. Some of the cost estimates underlying Table S–1 are based upon conceptual designs or a partial understanding of the technical requirements for processing the spent nuclear fuel or qualifying the high-level radioactive waste products. These uncertainties are sufficiently large to make it difficult to differentiate between the costs for Alternatives 1 through 3 and Alternatives 4 through 6.

For these reasons, the relative differences in the costs shown in Table S–1 for the respective alternatives should not be regarded as the sole basis for, or even the dominant factor in, choosing one alternative over another.

For Alternatives 1, 2 and 3, which do not involve melting and diluting the spent nuclear fuel, the net present values of the costs are difficult to distinguish. Uncertainties associated with Alternative 2 include the requirements for filling, inerting, and testing the high-integrity cans, as well as qualification and repository certification of the fuel in the high-integrity cans. Alternative 3 has risks (which are not quantified) concerning the availability of PUREX processing at the SRS F-Canyon. Alternatives 4 and 6, which involve melting and diluting the spent nuclear fuel, have uncertainties associated with the development, installation, and testing of new furnaces and off-gas systems at ANL-W. Alternative 5 has uncertainties associated with the need to redesign the melt and dilute off-gas system at SRS due to higher temperature requirements. All of the alternatives also have some uncertainties over waste form qualification.

Table S-2 provides a different approach to understanding the costs. It shows the net present values of the costs for each alternative by DOE site (INTEC, ANL-W, and SRS) and by waste disposal costs (high-level radioactive waste, transuranic waste, and low-level radioactive waste).

Table S–2 Cost by Site and Waste Disposal Charge (Millions of Year-2000 Dollars)

Alternatives	*INTEC*	*ANL-W*	*SRS*	*High-Level Radioactive Waste*	*Transuranic Waste*	*Low-Level Radioactive Waste*	*Total*
No Action Alternative: Direct disposal	16	340	0	87	less than 1	less than 1	443
Alternative 1: Electrometallurgical treatment of driver and blanket spent nuclear fuel at ANL-W	12	545	0	47	less than 1	less than 1	604
Alternative 2: Electrometallurgical treatment of driver spent nuclear fuel with sodium removal and package blanket spent nuclear fuel in high-integrity cans at ANL-W	10	469	0	33	less than 1	less than 1	512
Alternative 3: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and PUREX process blanket spent nuclear fuel at SRS	8	448	75	14	1	1	545
Alternative 4: Electrometallurgical treatment of driver spent nuclear fuel and melt and dilute blanket spent nuclear fuel at ANL-W	13	622	0	51	less than 1	less than 1	686
Alternative 5: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and melt and dilute blanket spent nuclear fuel at SRS	8	447	165	66	less than 1	less than 1	686
Alternative 6: Melt and dilute driver and blanket spent nuclear fuel at ANL-W	14	669	0	69	less than 1	less than 1	753

Table S-2 shows that overall program costs are determined by, and are subject to variation from, the costs for activities at ANL-W and SRS and the disposal of high-level radioactive waste. While costs at INTEC are significant, they do not vary significantly from alternative to alternative. Costs for disposal of transuranic waste (which are charged incrementally) and costs for disposal of low-level radioactive waste are insignificant. Table S-2 shows that a detailed understanding of the costs and uncertainties associated with operations at ANL-W and SRS and the generation and disposal of high-level radioactive waste is central to understanding the costs for the sodium-bonded spent nuclear fuel program.

A final way of considering the costs of the sodium-bonded spent nuclear fuel program is by annual costs, including contingencies and escalation, in year-2000 dollars. This presentation is similar to that used for annual budgets. **Table S-3** shows the annual costs for each alternative from 2000 to 2006, which represents the majority of the costs of the program. A final column shows the total expenditure from 2007 to 2035.

An overall conclusion that could be made is that the costs of Alternatives 1, 2, and 3 and Alternatives 4, 5, and 6 are similar, and that differences in preferences related to technical uncertainties, risks, timing of expenditures, potential compliance with the waste form acceptance criteria, and other factors are central to DOE's decision-making process regarding the SBSNF EIS.

Table S–3 Annual Costs 2000 to 2006 and Beyond
(Thousands of FY 2000 Dollars, Including Contingencies and Escalation)

Alternatives	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007-2035*
No Action Alternative: Direct disposal	44,150	45,599	40,383	36,620	28,582	26,159	18,957	177,330
Alternative 1: Electrometallurgical treatment of driver and blanket spent nuclear fuel at ANL-W	47,115	49,734	50,549	47,457	44,976	43,158	38,729	176,785
Alternative 2: Electrometallurgical treatment of driver spent nuclear fuel with sodium removal and package blanket spent nuclear fuel in high-integrity cans at ANL-W	48,575	56,535	60,402	56,661	53,908	50,090	43,051	60,196
Alternative 3: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and PUREX process blanket spent nuclear fuel at SRS	46,975	53,399	55,792	52,144	49,917	47,825	42,443	49,179
Alternative 4: Electrometallurgical treatment of driver spent nuclear fuel and melt and dilute blanket spent nuclear fuel at ANL-W	49,425	66,168	73,991	69,621	70,989	65,162	57,245	115,062
Alternative 5: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and melt and dilute blanket spent nuclear fuel at SRS	46,975	53,399	55,792	52,144	49,917	47,825	42,443	252,497
Alternative 6: Melt and dilute driver and blanket spent nuclear fuel at ANL-W	47,180	63,914	66,832	68,854	66,783	60,778	55,536	195,555

1. Overview

1.1 Introduction

In July 1999, DOE issued the SBSNF Draft EIS, which identifies potential alternatives for the proposed treatment and management of DOE-owned sodium-bonded spent nuclear fuel and for facilitating its disposal in a geologic repository. This cost study estimates and compares the life-cycle cost of each of the treatment and management alternatives presented in the SBSNF Draft EIS. In addition, the cost study goes beyond the scope of the EIS to analyze the program costs for life-cycle management of the sodium-bonded spent nuclear fuel through potential disposition in a geologic repository. Consideration of these estimated life-cycle costs will aid DOE in the decision-making process, and may form a basis for initial planning for ultimate disposition.

The costs associated with six alternatives and a No Action Alternative are evaluated in this cost study. The various methods for the treatment and management of sodium-bonded spent nuclear fuel are described briefly in Section 1.3 of this cost study and in more detail in the SBSNF Draft EIS.

The cost study is divided into three sections and six appendices. Section 1 contains the introduction, some background, a description of the alternatives, the methodology used to estimate the costs, and a discussion of the cost elements and assumptions used to conduct the cost analysis. The costs associated with each alternative (including the No Action Alternative) are addressed in Section 2. The life-cycle costs of each alternative are summarized in Section 3.

Appendix A provides background information on decladding and sodium cleaning and the basis for estimating the costs associated with these activities. Appendix B provides details on the basis used to estimate operating costs at ANL-W, SRS, and the Idaho Nuclear Technology and Engineering Center (INTEC). Appendix C provides cost estimates for two treatment technologies (i.e., GMODS and plasma arc) that are at an early developmental stage and have the potential to treat sodium-bonded spent nuclear fuels. These technologies were considered in the SBSNF Draft EIS and were dismissed. Appendix D describes the approach used to develop contingency estimates and provides a summary table showing contingencies by major cost element at each site. Appendix E provides technical background on waste form qualification requirements and contingencies. Appendix F discusses program costs over time, including a tabular presentation of costs on a net present value basis and costs on an undiscounted year-by-year basis. Summary tables are provided for the alternatives both as a group and for major cost elements at ANL-W over the period between 2000 and 2009.

1.2 Background

For nearly four decades, research, development, and demonstration activities associated with liquid metal fast breeder reactors were conducted at the Experimental Breeder Reactor-II (EBR-II) near Idaho Falls, Idaho; the Enrico Fermi Atomic Power Plant at Monroe, Michigan; and the Fast Flux Test Facility at the Hanford Site in Richland, Washington. These activities generated approximately 60 metric tons of heavy metal of sodium-bonded spent nuclear fuel for which DOE is now responsible.

Sodium-bonded spent nuclear fuel is distinguished from commercial nuclear reactor spent nuclear fuel by the presence of metallic sodium, a highly reactive material; frequently by metallic uranium, which is also potentially reactive; and in some cases, highly enriched uranium. Metallic sodium in particular presents challenges for management and ultimate disposal of this spent nuclear fuel. For example, metallic sodium reacts with water to produce explosive hydrogen gas and corrosive sodium hydroxide; both could affect the operation of a geologic repository.

In the SBSNF Draft EIS, DOE proposes (1) to treat and manage the sodium-bonded spent nuclear fuel and (2) to facilitate its ultimate disposal in a geologic repository. The reasonable alternatives for this proposed action are determined by the technology options available to DOE. Several technologies that might be used to treat and manage DOE's sodium-bonded spent nuclear fuel are at various stages of development. These include: (1) an electrometallurgical treatment process; (2) the plutonium-uranium extraction (PUREX) process; (3) placement of the spent nuclear fuel in high-integrity cans; (4) a melt and dilute process; (5) a glass material oxidation and dissolution system (GMODS) process; (6) a direct plasma arc-vitreous ceramic process; and (7) a chloride volatility process.

The programmatic risk associated with implementing any of these potential alternatives for treating and managing the sodium-bonded spent nuclear fuel, or with not treating the fuel, is the uncertainty surrounding the acceptability of DOE spent nuclear fuel for placement in a potential geologic repository. While DOE has drafted preliminary waste acceptance criteria[1], the final acceptance criteria will be more refined. If the repository is developed, the final acceptance criteria will not be available until after DOE receives its construction authorization from the U.S. Nuclear Regulatory Commission (NRC), based on the successful demonstration of the safe, long-term performance of the repository in accordance with the NRC regulations. Until such time, the preliminary acceptance criteria will tend to be conservative to allow for uncertainties in the performance of engineered and natural barriers and how such performance might impact public and worker health and safety, as well as material isolation.

The SBSNF Draft EIS follows the June 1, 1995, Record of Decision (60 FR 28680) for the *Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement* (Programmatic Spent Nuclear Fuel EIS), in which DOE decided to regionalize the management of DOE-owned spent nuclear fuel by fuel type. DOE also decided to: (1) continue environmental restoration activities at Idaho National Engineering and Environmental Laboratory (INEEL); (2) develop cost-effective treatment technologies for spent nuclear fuel and waste management; and (3) implement projects and facilities to prepare waste and treat spent nuclear fuel for interim storage and final disposition. This Record of Decision was based partially on the conclusions of the Programmatic Spent Nuclear Fuel EIS, which analyzed the potential environmental consequences of alternatives for transporting, receiving, processing, and storing spent nuclear fuel under DOE's responsibility for the next 40 years. It also analyzed the consequences of 10 years of waste and spent nuclear fuel management and environmental restoration actions at Idaho National Engineering Laboratory.[2]

In addition, DOE committed to removing all spent nuclear fuel from Idaho by 2035 in a 1995 agreement with the State of Idaho [Settlement Agreement and Consent Order (Idaho 1995) issued on October 17, 1995, in the actions of *Public Service Co. of Colorado v. Batt,* No. CV 91-0035-S-EJL (D. Id.), and *United States v. Batt*, No. CV 91-0054-EJL (D. Id.)]. Currently, more than 98 percent of DOE's sodium-bonded spent nuclear fuel is located at INEEL near Idaho Falls, Idaho, and is subject to the requirements of this Settlement Agreement and Consent Order. Before sodium-bonded spent nuclear fuel can be removed from the State of Idaho for ultimate disposal, some or all of the fuel may require treatment.

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[1] *Civilian Radioactive Waste Management System - Waste Acceptance System Requirements Document, 1998.*

[2] *The laboratory's name was changed to Idaho National Engineering and Environmental Laboratory in January 1997.*

1.3 DESCRIPTION OF ALTERNATIVES

The proposed action discussed in the SBSNF Draft EIS is to treat and manage DOE's sodium-bonded spent nuclear fuel. The alternatives for the proposed action are illustrated in **Figure 1–1** and are briefly described below.

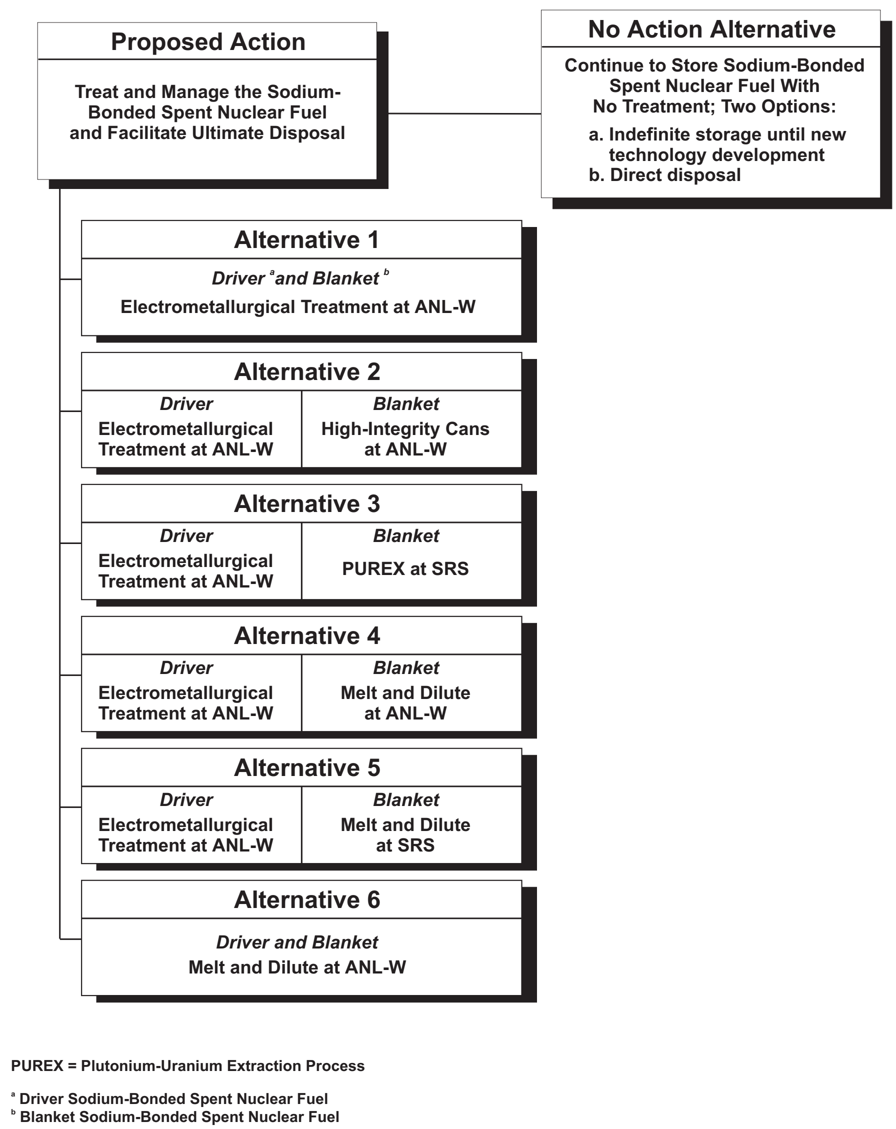

Figure 1–1 Proposed Action and Alternatives

1.3.1 No Action Alternative

Under the No Action Alternative, the sodium-bonded spent nuclear fuel would not be treated (no sodium would be removed) except for stabilization activities that may be necessary to prevent potential degradation of some of the spent nuclear fuel. Under the No Action Alternative, two options were considered: (1) the sodium-bonded spent nuclear fuel would continue to be stored indefinitely at its current location in accordance with the Record of Decision (60 FR 28680) for the Programmatic Spent Nuclear Fuel EIS (DOE 1995) and other existing site-specific National Environmental Policy Act (NEPA) documentation, or until another technology currently dismissed from consideration as a reasonable alternative because of immaturity (i.e., GMODS or plasma arc) is developed, and (2) the sodium-bonded spent nuclear fuel would be disposed of directly in a geologic repository without treatment, i.e., the fuel would be packaged in high-integrity cans with minimal preparation (cleaning and conditioning) and without sodium removal. To minimize costs and more effectively use the ANL-W and INTEC facilities, packaging for disposal would take place at ANL-W.

In selecting option one of the No Action Alternative, DOE could actively pursue research and development of another treatment technology including, for example, the GMODS and plasma arc methods. These methods offer the potential to treat both blanket and driver spent nuclear fuels and require minimal preconditioning of the sodium-bonded spent nuclear fuel. They do not involve separation of uranium or plutonium, and the treatment product is expected to be suitable for disposal in a geologic repository. While the environmental impacts of these treatment methods were not evaluated in the SBSNF Draft EIS, a rough cost estimate for the development and implementation of these technologies is provided in Appendix C.

1.3.2 Alternative 1: Electrometallurgical Treatment of Blanket and Driver Spent Nuclear Fuel at ANL-W

Under this alternative, the blanket and driver spent nuclear fuel from ANL-W's Radioactive Scrap and Waste Facility and the Hot Fuel Examination Facility would be transported directly to the Fuel Conditioning Facility for electrometallurgical treatment. Spent nuclear fuel currently stored at INTEC would be transported to the Hot Fuel Examination Facility. This would be necessary because only the Hot Fuel Examination Facility at ANL-W is capable of accepting spent nuclear fuel transportation casks. At the Hot Fuel Examination Facility, the spent fuel would be separated from the subassembly hardware and packaged and transferred to the Fuel Conditioning Facility for electrometallurgical treatment. The separated hardware would be packaged and managed as low-level radioactive waste.

After treatment, the low-enriched uranium by-product would be metal-cast at the Fuel Conditioning Facility and transferred to the Zero Power Physics Reactor Materials Storage Building for storage. The remaining cladding hulls would be packaged and transferred to the Hot Fuel Examination Facility for metal casting into high-level radioactive waste and afterwards would be transferred to the Radioactive Scrap and Waste Facility for storage. The electrorefiner salt containing the fission products, sodium, and transuranic elements would be transferred in metallic cans back to the Hot Fuel Examination Facility where the ceramic waste would be produced. The ceramic waste cylinders would be packaged and transferred to the Radioactive Scrap and Waste Facility for storage. Implementing this alternative at the Fuel Conditioning Facility and the Hot Fuel Examination Facility would require the installation of some new waste-handling equipment at the facilities. Electrometallurgical treatment of the sodium-bonded spent nuclear fuel at ANL-W could start as early as the year 2000, and would require approximately 12 to 13 years to process all fuel. Driver spent nuclear fuel alone would require approximately 7 years.

1.3.3 Alternative 2: Remove Sodium and Package Blanket Spent Nuclear Fuel in High-Integrity Cans and Electrometallurgically Treat Driver Spent Nuclear Fuel at ANL-W

Under this alternative, the blanket spent nuclear fuel elements (approximately 57 metric tons of heavy metal) would be packaged in high-integrity stainless steel cans at ANL-W after removal of the sodium without decladding. The driver spent nuclear fuel (approximately 3 metric tons of heavy metal, excluding approximately 0.08 metric tons of heavy metal in carbide fuels) would be treated using the electrometallurgical treatment process described in Section 1.3.2 (Alternative 1).

Removal of the sodium from the blanket spent nuclear fuel would take place at the Hot Fuel Examination Facility at ANL-W. The packaging in high-integrity cans would take place in the same facility. The high-integrity cans would be transferred to the Radioactive Scrap and Waste Facility for storage.

Implementing this alternative at either the Fuel Conditioning Facility or the Hot Fuel Examination Facility would require the installation of equipment for sodium removal activities. The installation of some new waste-handling equipment also would be needed for the electrometallurgical treatment of the driver spent nuclear fuel.

Packaging the blanket spent nuclear fuel in high-integrity cans could start by approximately 2003. It would take approximately six years to complete. Electrometallurgical treatment of the driver spent nuclear fuel would start in 2000 and would be completed in approximately seven years.

1.3.4 Alternative 3: Declad and Clean Blanket Spent Nuclear Fuel and Electrometallurgically Treat Driver Spent Nuclear Fuel at ANL-W; PUREX Process Blanket Spent Nuclear Fuel at SRS

Under this alternative, the blanket spent nuclear fuel pins (approximately 57 metric tons of heavy metal) would be packaged in aluminum cans and shipped to SRS for treatment using the PUREX process at the SRS F-Canyon facility. The blanket spent nuclear fuel pins would be separated from the cladding and cleaned to remove the metallic sodium at ANL-W.

The driver spent nuclear fuel (approximately 3 metric tons of heavy metal) would be treated at ANL-W using the electrometallurgical treatment processes described in Section 1.3.2 for Alternative 1. Decladding of the blanket spent nuclear fuel and sodium removal could take place at the Hot Fuel Examination Facility at ANL-W. Equipment for decladding and sodium removal would need to be installed for this purpose. After decladding and sodium removal, the blanket spent nuclear fuel pins would be packaged and stored temporarily at the Hot Fuel Examination Facility pending shipment to SRS.

At SRS, the cans containing blanket spent nuclear fuel pins would be stored at L-Basin before being transported to the F-Canyon facility for treatment using the PUREX process. No modifications to that facility would be needed. Waste from the process containing the fission products and transuranic isotopes other than plutonium would be transferred to the Defense Waste Processing Facility where it would be converted to borosilicate glass logs and stored pending ultimate disposal. Separated plutonium in metal form would be stored in an SRS vault. Depleted uranium would be transferred to a storage yard for depleted uranium at the site.

Considering the commitment of F-Canyon to other DOE missions, PUREX processing of the blanket spent nuclear fuel would start no earlier than 2005 and would last less than one year. Decladding and sodium removal activities at ANL-W would not start earlier than 2003. Therefore, these activities would determine the length of the process. For cost analysis purposes, decladding, sodium removal, and shipment to SRS are assumed to take place over the 2004 to 2009 time period. When SRS has received all the declad and cleaned sodium-bonded spent nuclear fuel, a six-month PUREX processing campaign at F-Canyon would begin. As in the case of Alternative 2, electrometallurgical treatment of the driver spent nuclear fuel could start in 2000 and could be completed in approximately seven years.

1.3.5 Alternative 4: Melt and Dilute Blanket Spent Nuclear Fuel and Electrometallurgically Treat Driver Spent Nuclear Fuel at ANL-W

Under this alternative, the blanket spent nuclear fuel elements (approximately 57 metric tons of heavy metal) would be treated at ANL-W using the melt and dilute treatment process. Prior to treatment, the metallic sodium would be removed without decladding at ANL-W.

The driver spent nuclear fuel (approximately 3 metric tons of heavy metal) would be treated at ANL-W using the electrometallurgical treatment process described in Section 1.3.2 for Alternative 1.

Removal of the sodium from the blanket spent nuclear fuel could take place at the Hot Fuel Examination Facility at ANL-W. Equipment for sodium removal would need to be installed at the facility. Equipment necessary for the melt and dilute process also would need to be installed at the facility, including the addition of the melter and an off-gas system.

Metal waste resulting from the melt and dilute process containing fission products, depleted uranium, and transuranic elements would be transferred to the Radioactive Scrap and Waste Facility for storage pending ultimate disposal.

Treatment of the blanket spent nuclear fuel at ANL-W using the melt and dilute process could start as early as 2005 and could be completed in seven years. Treatment of the driver spent nuclear fuel could start as early as 2000 and could be completed in approximately seven years.

1.3.6 Alternative 5: Declad and Clean Blanket Spent Nuclear Fuel and Electrometallurgically Treat Driver Spent Nuclear Fuel at ANL-W; Melt and Dilute Blanket Spent Nuclear Fuel at SRS

Under this alternative, the blanket spent nuclear fuel pins (approximately 57 metric tons of heavy metal) would be packaged and shipped to SRS for treatment. The blanket spent nuclear fuel pins would be separated from the cladding and cleaned to remove the metallic sodium at ANL-W. The declad and cleaned blanket spent nuclear fuel pins would be received at the 105-L Building at SRS and treated using the melt and dilute treatment process.

The driver spent nuclear fuel (approximately 3 metric tons of heavy metal), excluding approximately 0.08 metric tons of heavy metal in carbide fuels, would be treated at ANL-W using the electrometallurgical treatment process described in Section 1.3.2 for Alternative 1.

Decladding of the blanket spent nuclear fuel and sodium removal would take place at the Hot Fuel Examination Facility at ANL-W. After decladding and sodium removal, the blanket spent nuclear fuel rods would be packaged and stored temporarily at the Hot Fuel Examination Facility pending shipment to SRS.

At SRS, the cans containing the cleaned and declad blanket spent nuclear fuel pins would be unpacked at the 105-L Building, and the blanket spent nuclear fuel pins would be treated using the melt and dilute process. For the purpose of evaluating this alternative, it was assumed that the melt and dilute facility is operational at SRS, as proposed in the *Savannah River Site Spent Nuclear Fuel Environmental Impact Statement.* Some new equipment in the off-gas control system may need to be installed at SRS before treating the spent nuclear fuel.

Metal waste resulting from the melt and dilute process containing fission products, depleted uranium, and transuranic elements would be stored in L-Area pending ultimate disposal.

Treatment of the driver spent nuclear fuel at ANL-W could start in 2000 and could be completed in approximately seven years. For cost analysis purposes, treatment of the blanket spent nuclear fuel at SRS is assumed to start in 2022. This start date is based on existing DOE commitments through 2020, and one additional year of equipment upgrades and testing to prepare for treating sodium-bonded spent nuclear fuel. It is also possible that treatment could be deferred to 2035 because of commitments to other programs involving melt and dilute processing at Building 105-L. The treatment process would last approximately three years.

1.3.7 Alternative 6: Melt and Dilute Driver and Blanket Spent Nuclear Fuel at ANL-W

Under this alternative, the blanket and driver spent nuclear fuel would be treated in the Hot Fuel Examination Facility at ANL-W using the melt and dilute treatment process.

Removal of the sodium from the blanket spent nuclear fuel would take place at the Hot Fuel Examination Facility. Equipment for sodium removal activities and the melt and dilute process would need to be installed in the inert cell of the facility.

The metal waste resulting from the melt and dilute process containing fission products, depleted uranium, and transuranic elements would be transferred to the Radioactive Scrap and Waste Facility for storage pending ultimate disposal.

The melt and dilute process at ANL-W could start as early as 2005 and would take approximately 10 years to be completed for all blanket and driver spent nuclear fuels.

1.4 METHODOLOGY

Cost estimates presented in this study are based on discussions with personnel at ANL-W, SRS, INEEL's INTEC, the National Spent Nuclear Fuel Program, DOE headquarters, and DOE support contractors. Estimates are based on facility availability and the duration of each major activity as outlined in the SBSNF Draft EIS. Major activities include cleaning the sodium from blanket spent nuclear fuel assemblies at ANL-W (Alternatives 2 through 6); decladding the blanket spent nuclear fuel assemblies for shipment to SRS (Alternatives 3 and 5); ongoing research and development of treatment technologies (all alternatives); design, engineering, installation, and testing of new equipment (all alternatives); and storage and packaging of waste forms for disposal (all alternatives).

Annual operating and equipment costs are presented as nominal, current-year estimates except where life-cycle costs are noted. The net present values of the life-cycle costs, expressed in year-2000 dollars, including contingencies, are based on a nominal escalation rate of 2.8 percent (INEEL 1999c) and a nominal discount rate of 4.9 percent (OMB 1999).

The first step in the process of developing this cost study was to determine the major elements of each alternative, including the packaging and shipping of the sodium-bonded spent nuclear fuel from INTEC to ANL-W and from ANL-W to SRS, the treatment of the spent nuclear fuel at ANL-W and/or SRS, and the management and handling of all waste forms in preparation for ultimate disposal. These elements are presented in Section 1.5.

The second step was to work with technical personnel at ANL-W, SRS, and INTEC to break down the major elements of each alternative into the functional processing units used by the sites to determine their operating costs. At ANL-W, major elements were divided into base operations, equipment operations, technical support, and equipment. All facilities were grouped together. At SRS, the major elements were arranged by facility rather than function. F-Canyon, L-Basin, Building 105-L, and the Defense Waste Processing Facility were addressed as functional units rather than by base operations, equipment operations, technical support, and equipment. At INTEC, the major elements were combined first into preparation and packaging costs for shipment to ANL-W for processing and then into preparation and packaging costs for shipment and disposal of high-level radioactive waste at a repository. Appendix B provides a detailed discussion of the basis for the operating costs at each of the three sites.

The third step was to develop spreadsheets keyed to functional processing units to produce total costs by site, year, and major element. Appendices D and F provide details on contingencies and annual costs, respectively.

The fourth step was to review the costs, assumptions, contingencies, and uncertainties for each major element with technical personnel at ANL-W, INTEC, and SRS to determine consistent approaches to contingencies and other inputs.

1.5 Cost Elements and Assumptions

The following cost elements and assumptions were used in developing the estimates presented in this study. These elements and assumptions were based on decisions made by DOE in the preparation of the SBSNF Draft EIS. Unless otherwise cited, detailed operating, equipment, and staffing costs at ANL-W were based on data provided by ANL (ANL 1999). Escalated and discounted life-cycle costs at ANL-W were developed separately from these line-item costs. Citations for costs for SRS and INTEC, as well as waste disposal, are provided in the relevant sections.

Costs discussed as individual program elements in the text (e.g., shipping from INTEC, processing at ANL-W or SRS, and waste disposal) exclude inflation, escalation, contingencies, and discounting. Costs shown as net present values on the summary tables (i.e., constant year-2000 dollars) include inflation, escalation, contingencies, and discounting. Differences between these cost figures may be large, especially when contingencies are high or the costs are incurred in the early years of the program. Appendices D and F provide details on these issues.

1.5.1 Packaging and Shipping

Approximately half of the sodium-bonded spent nuclear fuel subject to treatment is currently stored at INTEC. This material would be packaged and transferred to ANL-W for further treatment. The cost for these activities, which are common to all alternatives under the proposed action and the direct disposal option of the No Action Alternative, is estimated to be $6.1 million (INEEL 1999a). Major components of this cost are shown in **Table 1–1**.

Table 1–1 Packaging and Shipping

Fuel	*Activity at INTEC (year)*	*Cost in Millions of Dollars*
EBR-II	Prepare transfer from Irradiated Fuel Storage Facility to ANL-W (2000 to 2001)	1.3
EBR-II	Transfer to ANL-W (2002 to 2004)[a]	3.6
Fermi-1	Prepare transfer from CPP-749 to ANL-W (2005)[a]	0.2
Fermi-1	Transfer to ANL-W (2005 to 2007)[a]	1.0
Total		6.1

CPP = Chemical Processing Plant

[a] To efficiently use the ANL-W facilities under the direct disposal of the No Action Alternative, packaging and transfer activities at INTEC could be accelerated by as much as two years.

Source: INEEL 1999a.

Costs for packaging and shipment between the Fuel Conditioning Facility, the Hot Fuel Examination Facility, and the Radioactive Scrap and Waste Facility are included in the operating costs at ANL-W. Packaging costs prior to shipment of cleaned and declad spent nuclear fuel to SRS also are included in the ANL-W operating costs.

The full cost to package and store the spent nuclear fuel and high-level radioactive waste at ANL-W or SRS prior to packaging and shipment to a repository is included in the operating costs of those sites.

Shipment of 950 cans containing clean and declad blanket spent nuclear fuel pins to SRS, as identified in Alternatives 3 and 5, is estimated to cost $1.3 million. This cost is based on 28 truck shipments at $18,000 per shipment for the truck and operator and $28,000 per shipment for the cask (using a standard spent nuclear fuel shipping cask for a 14-day round trip at $2,000 per day).

Costs for packaging and shipping materials from Hanford, Oak Ridge, and Sandia to INEEL are estimated collectively at less than $1 million and are not itemized in this cost study. These costs would be identical for each of the alternatives.

Under all alternatives, the waste forms in interim storage at ANL-W would be transferred to INTEC for repackaging into repository disposal packages. INEEL is in the process of evaluating bids for a high-level radioactive waste dry transfer and packaging facility. This facility is proposed to accept the high-level radioactive waste generated at ANL-W for repackaging into road-ready repository disposal packages. Using the current planning basis for the dry transfer facility, this cost study estimates the major cost components for high-level radioactive waste receiving and packaging at INTEC as shown below (INEEL 1999b). Packaging loads and costs are based on nine standard canisters per disposal package (i.e., cask).

- Fixed costs — $500,000 per waste type
- Canister receiving and interim dry storage — $360,000 per cask
- Cask packaging and loading for shipping — $63,000 per cask
- Cleanup, including shipping cask decontamination — $36,000 per cask

1.5.2 Treatment and Storage

The treatment and storage costs include the operating costs at the proposed sites and the equipment and facility upgrade costs necessary to implement the treatment alternative. Operating costs at ANL-W, SRS, and INTEC are based on information presented in Appendix B. Costs associated with sodium cleaning and decladding activities are based on information provided in Appendix A.

1.5.3 Waste Form Qualification

Waste form qualification costs (whether for spent nuclear fuel or processed wastes) are estimated at a combined total of about $47 million for the metal and ceramic waste forms of the electrometallurgical treatment process and $15 million each for all other waste forms. The $15 million value is a rough estimate used by the National Spent Nuclear Fuel Program. The $47 million value is based on the ongoing Electrometallurgical Treatment Demonstration Project at ANL-W. Because existing electrometallurgical treatment wastes from this demonstration will require qualification regardless of the alternative selected by the SBSNF EIS, this cost applies to each alternative. Appendix E discusses these issues in detail. Waste form qualification costs are assumed to be incurred over a multiyear period a few years before the end of processing for each alternative.

1.5.4 Disposal Fees

The Civilian Radioactive Waste Management System allocates costs on a full-cost recovery basis. All spent nuclear fuel and high-level radioactive waste proposed for repository disposal is charged a unit cost based on the total system life-cycle cost for the repository program. DOE currently estimates the total system life-cycle cost of the repository program at $43.6 billion, including onsite storage, transportation, and contingencies. DOE estimates that its share of the costs is about 24.7 percent, or about $10.8 billion for 23,861 standard canisters (DOE 1998). Allocating $10.8 billion over 23,861 standard canisters translates to about $452,000 per canister. This cost study uses $475,000 per canister as the current fixed repository cost expressed in year-2000 dollars. At this unit cost, high-level radioactive waste disposal is a major factor affecting the costs of each alternative. The contribution of high-level waste disposal costs to total program costs is explained in Section 2.

Alternatives 1 through 4 and 6 are assumed to include repository packaging and disposal fees in 2015, while Alternative 5 and the direct disposal option under the No Action Alternative are assumed to include repository packaging and disposal fees in 2024 and 2035, respectively. To address the differences in costs for widely different disposal periods, this cost study inflates (not escalates) the $475,000 per canister charge by 2.8 percent and discounts it by 4.9 percent. These rates are used universally throughout the cost study. The discounting approach has no relative impact on the net present values presented for Alternatives 1 through 4 and 6, but slightly overstates the net present value of the costs for Alternative 5 and the direct disposal option under the No Action Alternative.

For disposal of transuranic waste at the Waste Isolation Pilot Plant, DOE has specified an incremental cost approach. Incremental transportation and disposal fees are about $17,500 per shipment (converted to year-2000 dollars) for both contact-handled and remote-handled transuranic waste (DOE 1997c). Shipments are estimated to contain approximately 6 cubic meters of contact-handled transuranic waste or 0.6 cubic meters of remote-handled transuranic waste. The allocation of transuranic waste among the alternatives is approximately 50 percent contact-handled and 50 percent remote-handled, except in the direct disposal option of the No Action Alternative, where it is about 30 percent contact-handled and about 70 percent remote-handled. Because the costs for disposal of transuranic waste are allocated incrementally (unlike high-level radioactive waste disposal costs) and the quantities of transuranic waste generated in processing the sodium-bonded spent nuclear fuel are small, the total transuranic waste disposal costs are low. Transuranic waste disposal costs are slightly less than $1 million in Alternative 3, and significantly less than $0.5 million in each of the other alternatives and the direct disposal option of the No Action Alternative.

Low-level radioactive wastes are assessed at $290 per cubic meter (DOE 1996). Total low-level radioactive waste disposal costs also are insignificant in each alternative. **Table 1–2** provides the quantities of high-level radioactive, low-level radioactive, and transuranic wastes that would be generated by each alternative as presented in the SBSNF Draft EIS.

Table 1–2 Comparison of Wastes Generated By Each Alternative

Alternative	*High-Level Radio-active (cubic meters)*	*High-Level Radioactive Standard Canisters at ANL-W*	*High-Level Radioactive Standard Canisters at SRS*	*Low-Level Radioactive (cubic meters)*	*Trans-uranic (cubic meters)*
No Action Alternative: Direct disposal	152	371	NA	812	10
Alternative 1: Electrometallurgical treatment of driver and blanket spent nuclear fuel at ANL-W	84	135	NA	861	14
Alternative 2: Electrometallurgical treatment of driver spent nuclear fuel with sodium removal and package blanket spent nuclear fuel in high-integrity cans at ANL-W	44	93	NA	734	11
Alternative 3: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and PUREX process blanket spent nuclear fuel at SRS	24	30	9	2,961	101
Alternative 4: Electrometallurgical treatment of driver spent nuclear fuel and melt and dilute blanket spent nuclear fuel at ANL-W	64	144	NA	828	13
Alternative 5: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and melt and dilute blanket spent nuclear fuel at SRS	95	30	190	1,179	23
Alternative 6: Melt and dilute driver and blanket spent nuclear fuel at ANL-W	86	197	NA	924	14

NA=Not applicable.

1.5.5 Deactivation Costs

Each of the alternatives, including the No Action Alternative, includes deactivation and waste cleanup from the ongoing electrometallurgical treatment demonstration. Any new equipment to support the treatment and management of sodium-bonded spent nuclear fuel, e.g., melt and dilute processing at ANL-W, also would require deactivation. For each alternative, one year of operating costs at ANL-W is added following the last full year of processing operations for the deactivation and safe closure of the equipment and materials used for processing. This cost study assumes that one year of operating costs is a reasonable estimate of the work and staffing requirements for facilities and equipment operation related to the deactivation. It is not meant to be a detailed, engineering-based estimate of the precise technical and labor requirements. No deactivation costs are incurred at SRS or INTEC.

1.5.6 Separated Uranium/Plutonium Management

The heavy metal mass of high-level radioactive waste in the various alternatives depends on how the sodium-bonded spent nuclear fuel is treated. In Alternatives 1 and 3, almost all of the uranium would be separated out of the waste stream. For Alternatives 1 through 5, the entire highly enriched uranium mass of the driver spent nuclear fuel assemblies, separated using electrometallurgical treatment, would be blended down to low enriched uranium. The depleted uranium in the blanket spent nuclear fuel would be separated only in Alternatives 1 and 3, and would be part of the high-level radioactive waste in Alternatives 2, 4, and 5. The separated uranium would be available for use as feedstock. In Alternative 6, all the heavy metal would be metallic high-level radioactive waste.

In Alternative 1, plutonium would be captured in the ceramic waste for disposal in the repository. In Alternative 3, the plutonium would be separated and would be available for use as feedstock in the mixed-oxide fuel program. Alternatively, the separated plutonium could be disposed as a waste product. This cost study assumes that the plutonium would be immobilized for disposal.

Because no decision on the use of the separated uranium (i.e., low-enriched or depleted) would be made until well beyond the Record of Decision issued under the present EIS, it is impossible to know whether or how to value the uranium as a product or charge for its disposal. Because any value or charge would be small and the amount of separated uranium would be a very small percentage of DOE's inventory, no cost or credit is assigned to it.

1.5.7 Escalation and Discounting

Annual costs are escalated at a nominal rate of 2.8 percent (INEEL 1999c) and are discounted at a nominal rate of 4.9 percent (OMB 1999). The use of a 2.8 percent nominal rate of escalation and a 4.9 percent nominal rate of discount has the effect of creating a real discount rate of about 2 percent. Using a 2 percent rate, which is about one point lower than traditionally used, has the effect of making all of the net present values reported in this cost study appear higher than would be the case at a higher rate. Because of the timing of the expenditures and the deferral of costs in the direct disposal option under the No Action Alternative (and to a lesser degree Alternative 5), the low real discount rate understates the costs for these alternatives compared to Alternatives 1 through 4 and 6.

To estimate costs over time, it is necessary to develop integrated schedules for the major program elements. **Table 1–3** summarizes the integrated schedules used in the cost study.

Table 1–3 Integrated Schedules (Excluding Contingencies)

*Treatment Process (at ANL-W or SRS, as noted)**	*Material*	*Design, Engineer, Install, Test*	*Process & Package, Deactivate***	*Repository Packaging / Disposal*
No Action (Direct Disposal)	All	2000-2005	2001-2006	2035
Alt. 1 (Electrometallurgical Treatment)	All	2000	2000-2013	2015
Alt. 2 (Electrometallurgical Treatment)	Drivers	2000	2000-2006	2015
(Clean Sodium)	Blankets	2001-2003	2002-2009	Not applicable
(High-Integrity Cans)	Blankets	2001	2003-2009	2015
Alt. 3 (Electrometallurgical Treatment)	Drivers	2000	2000-2006	2015
(Declad & Clean)	Blankets	2001-2003	2003-2009	Not applicable
(PUREX @ SRS)	Blankets	2008	2009	2015
Alt. 4 (Electrometallurgical Treatment)	Drivers	2000	2000-2006	2015
(Clean Sodium)	Blankets	2001-2003	2002-2009	Not applicable
(Melt and Dilute)	Blankets	2001-2003	2004-2011	2015
Alt. 5 (Electrometallurgical Treatment)	Drivers	2000-2001	2000-2006	2015
(Declad & Clean)	Blankets	2001-2003	2003-2009	Not applicable
(Melt & Dilute at SRS)	Blankets	2021	2022-2024	2024
Alt. 6 (Melt & Dilute at ANL)	All	2001-2004	2004-2014	2015

*Shipments from INTEC to ANL-W take place in 2001 to 2007. Shipments from ANL-W to SRS take place in 2004 to 2009.
**Includes one year for deactivation of equipment and facilities cleanup at ANL-W after processing and packaging is completed.

1.5.8 Contingencies

This section discusses the contingencies expected to affect the cost, performance, and schedule of the proposed alternatives. These contingencies were quantified based on technical maturity and design certainty, and were added to the annual line-item costs to develop the net present value of the life-cycle costs. The contingencies presented in this cost study range from 10 to 60 percent and are similar to those used to estimate the costs for commercial power plants (EPRI 1989). Appendix D provides a detailed discussion of the basis for the contingency estimates and the application of contingencies to each program element. This appendix notes that one of the major implications of the contingency approach is to extend the expected duration of processing activities at ANL-W.

The contingencies used in this cost study were based upon a three-step approach developed by representatives of ANL-W, INTEC, the National Spent Nuclear Fuel Program, and Science Applications International Corporation in June 1999:

- For each alternative at ANL-W, costs associated with treatment and waste disposal were divided into operations and equipment categories. Operations were further divided into three other categories: (1) base (i.e., facilities), (2) technical support (i.e., engineering and support for the specific process), and (3) equipment (i.e., operational use of the specific process equipment).

- Within each cost category (three operations and one equipment), direct costs were estimated for major functions (e.g., treatment and management of spent nuclear fuel, waste disposal operations, and waste qualification).

- A contingency factor was assigned to each major function to reflect the maturity and certainty of the treatment technology or process.

Contingencies at SRS were based on similar processes at ANL-W (e.g., melt and dilute) and on the technical maturity and certainty for unique processes (e.g., PUREX processing at F-Canyon). Contingencies were assumed to range from 10 percent for fully mature processes to 60 percent for conceptual processes or processes for which no flow sheets, equipment specifications, and process specifications exist. These contingencies were applied to all activities at ANL-W, SRS, and INTEC except for (1) repackaging operations at INTEC's proposed dry transfer facility, which are assumed to be based on firm-fixed prices from a private vendor, and (2) disposal fees for high-level radioactive waste and transuranic waste, which are assumed to include contingencies comparable to those used in this cost study.

2. COST ANALYSIS

The costs for each alternative are described in the following sections. Costs discussed as individual program elements in the text (e.g., shipping from INTEC, processing at ANL-W or SRS, waste disposal) exclude inflation, escalation, contingencies, and discounting. Costs shown as net present values in the summary tables (i.e., constant year-2000 dollars) include inflation, escalation, contingencies, and discounting. Differences between the values in the text and the values in the tables may be large, especially when contingencies are high or costs are incurred in the later years of the program. Appendices D (Contingencies) and F (Costs Over Time) include details on these issues. Cost elements and assumptions to support these cost estimates are provided in Section 1.5.

2.1 NO ACTION ALTERNATIVE

The No Action Alternative has two options: (1) the sodium-bonded spent nuclear fuel would be disposed of directly in a geologic repository without treatment, and (2) the sodium-bonded spent nuclear fuel would continue to be stored indefinitely at current locations until a new or immature technology (i.e., GMODS or plasma arc) is developed. The indefinite storage option involves no treatment or endpoint for which costs can be estimated. Other processing technologies associated with this option, whether new or immature, are not discussed in this cost study as comparable treatment options. However, costs associated with these other processing technologies are briefly discussed in Appendix C.

2.1.1 Packaging and Shipping

Under the direct disposal option, the sodium-bonded spent nuclear fuel currently at INTEC would be shipped to ANL-W at a cost of approximately $6 million. At ANL-W, it would be packaged into cans at the Fuel Conditioning Facility and the Hot Fuel Examination Facility without removal of the sodium or treatment of the spent nuclear fuel. The canned sodium-bonded spent nuclear fuel would be shipped to the Radioactive Scrap and Waste Facility for interim storage. Assuming the canned sodium-bonded spent nuclear fuel would comply with the waste acceptance criteria, it would be shipped from the Radioactive Scrap and Waste Facility to a proposed dry transfer facility at INTEC for packaging into standard spent nuclear fuel shipping canisters in preparation for transport to the repository. The cost to ship the packaged spent nuclear fuel to INTEC for repackaging and repository disposal would be less than $1 million. Repackaging costs at INTEC for shipment to the repository are estimated at $10 million.

2.1.2 Storage

Equipment Costs

Equipment costs for the direct disposal option under the No Action Alternative are estimated at about $16.5 million, of which $10 million would be spent in the years 2000 to 2002 and an additional $0.5 million would be spent annually through the year 2035. A production-scale ceramic waste hot isostatic press would be installed during the years 2000 through 2001. Most of the equipment costs after this time would involve equipment to support waste processing and facility upgrades.

Operating Costs

Fuel stabilization activities for direct disposal would begin in 2003 or 2004 and would last three years, after which the remaining activities would be in support of storage until disposal. Operating costs of the direct disposal option under the No Action Alternative are estimated to range from $31 to $34 million from 2000 through 2003. Operating costs would decline to about $23 to 24 million in 2004 and 2005, $17 million in 2006, $8 million in 2007 to 2009, $6 million in 2010, and then would continue at $4 million annually until the sodium-bonded spent nuclear fuel is shipped offsite in 2035.

2.1.3 Waste Form Qualification

Qualification of untreated driver and blanket sodium-bonded spent nuclear fuel, in two waste forms, would cost $15 million each. Qualification of the two electrometallurgical treatment waste forms is estimated to total $47 million.

2.1.4 Disposal Fees

The direct disposal option under the No Action Alternative would require 371 standard disposal canisters. If the untreated sodium-bonded spent nuclear fuel complies with waste acceptance criteria, the repository fee for 371 high-level radioactive waste disposal canisters is estimated at $176 million. Disposal charges for transuranic and low-level radioactive waste would be insignificant.

2.1.5 Deactivation Costs

One year of operating costs at ANL-W would be added following the last full year of processing operations for the deactivation and safe closure of the equipment and materials used for both this alternative and for the existing electrometallurgical treatment equipment in the hot cells. After deactivation, a minimal staff would be required to maintain the storage of deactivated waste materials at the Radioactive Scrap and Waste Facility and the Hot Fuel Examination Facility. Deactivation costs, which are included in the operating costs summarized above, would amount to about $8 million in 2006.

2.1.6 Contingencies

Key technical uncertainties for the direct disposal option under the No Action Alternative include the absence of a clear disposal path and the effects of potential long-term dry storage. Degradation of the fuel elements and failure during dry storage cannot be ruled out. For example, during the Electrometallurgical Treatment Demonstration Project at ANL-W, one fuel can was found to contain a failed element. Fuel failures could complicate disposition options. Fuel reconfiguration, estimated to have a direct cost of about $20 million, is assigned a 40 percent contingency factor. The largest cost element under the No Action Alternative ($165 million out of a total ANL-W cost of $344 million) is facilities operation. This is a mature process and receives a 10 percent contingency factor. Appendix D discusses contingencies in detail.

2.1.7 Summary

The net present value of the direct disposal option under the No Action Alternative is estimated at $443 million. **Table 2–1** presents this total by major cost element and **Table 2–2** presents the costs by site. Appendix F summarizes related details by year for the years 2000 to 2009.

Table 2–1 Cost Summary for the No Action Alternative by Cost Element: Direct Disposal Option

Cost Elements	*Net Present Value in Millions of Year-2000 Dollars (including contingencies and escalation)*
Packaging and shipping	
INTEC to ANL-W	6
ANL-W to SRS	Not applicable
ANL-W to INTEC	less than 1
INTEC for a repository (packaging only)	10
SRS for a repository (packaging only)	Not applicable
Sodium cleaning and/or decladding	Not applicable
Treatment and storage	
Equipment at ANL-W	24
Operations at ANL-W	217
Equipment at SRS	Not applicable
Operations at SRS	Not applicable
Waste form qualification at ANL-W	91
Waste form qualification at SRS	Not applicable
Separated plutonium/uranium management	Not applicable
Disposal fees	
High-level radioactive waste	87
Transuranic waste	less than 1
Low-level radioactive waste	less than 1
Deactivation	8
Total	443

Table 2–2 Cost Summary for the No Action Alternative by Site: Direct Disposal Option

Site	*Cost in Net Present Value in Millions of Year-2000 Dollars*
INTEC	16
ANL-W	340
SRS	0
Other nonsite-related costs	87
Total	443

2.2 Alternative 1: Electrometallurgical Treatment of Blanket and Driver Spent Nuclear Fuel at ANL-W

2.2.1 Packaging and Shipping

Sodium-bonded spent nuclear fuel currently at INTEC would be shipped to ANL-W at a cost of approximately $6 million. The spent nuclear fuel would be processed at ANL-W using electrometallurgical treatment at the Fuel Conditioning Facility and the Hot Fuel Examination Facility. The cost to ship the processed high-level radioactive waste to INTEC for repackaging and repository disposal would be less than $1 million. The cost to package waste canisters at INTEC in 2015 for shipping to the repository is estimated at about $6 million.

2.2.2 Treatment and Storage

Equipment Costs

Major maintenance and facility upgrades (e.g., argon cell refrigeration system replacement, improvements to the overhead handling system repair area, remote handling system repairs) would take five months from issuance of the Record of Decision. Processing would begin at a reduced rate through the balance of the year 2000. Full annual processing rates would be achieved around June 2001. Full operations (24 hours per day on two 12-hour shifts) would require installation of an improved driver spent nuclear fuel element chopper, cathode processor modifications for larger blanket spent nuclear fuel batches, and new controls for the electrorefiner. Facility modifications include a new rapid insertion port, overhead handling system upgrades, cask unloading equipment for old Radioactive Scrap and Waste Facility blanket fuels and Fermi-1 fuels, and computer control system improvements. Equipment costs at the Fuel Conditioning Facility and the Hot Fuel Examination Facility for this alternative are estimated at about $30 million. Of this total, about $12 million would be required in the 2000 to 2002 period.

Operating Costs

For waste operations, demonstration-scale equipment to support waste process and waste form qualification testing would be operated until September 2000. From October 2000 through June 2001, larger-scale ceramic waste equipment (i.e., a V-mixer, hot isostatic press, and metal casting furnace) would be installed. Following waste form qualification testing, full capacity waste operations would start in June 2002.

Treatment and waste processes require technical support to improve throughput, minimize costs, and solve problems. Waste processing and qualification activities will initially emphasize data requirements for the repository license application and full-scale process qualification. These activities are expected to require the present level of effort through October 2002 and gradually be reduced to a support level by October 2005. Annual operating costs are estimated in the range of $35 to $41 million from 2000 to 2010, about $31 million from 2011 to 2013, and about $3 million from 2014 to 2015.

2.2.3 Waste Form Qualification

An Electrometallurgical Treatment Demonstration Project has been in operation at ANL-W since June 1996 and is planned to continue through the fall of 1999. After the electrometallurgical treatment demonstration is completed, ongoing operations will focus on waste form qualifications. Waste form qualifications would be conducted in parallel with full-scale treatment of the sodium-bonded spent nuclear fuel. The waste form qualification cost is estimated at $52 million.

2.2.4 Disposal Fees

Alternative 1 would generate 135 standard high-level radioactive waste disposal canisters. The repository fee in 2015 for these canisters would be about $64 million. Disposal charges for transuranic waste and low-level radioactive waste would be insignificant.

2.2.5 Deactivation Costs

One year of operating costs at ANL-W would be added following the last full year of processing operations for the deactivation and safe closure of the equipment and materials used for this alternative and for the existing electrometallurgical treatment equipment in the hot cells. After deactivation, a minimal staff would be required to maintain the storage of deactivated waste materials at the Radioactive Scrap and Waste Facility and the Hot Fuel Examination Facility. Deactivation costs, which are included in the operating costs summarized above, would amount to about $28 million in 2013.

2.2.6 Contingencies

A moderate amount of new equipment and facilities upgrades would be required to complete the electrometallurgical treatment processing system. Ramping up to full production rates from the current demonstration-scale operations is expected to take considerable time and technical support. Waste form qualification is among the more uncertain technical issues. Approximately half of the operating costs at ANL-W for Alternative 1 would be for mature processes, such as facilities operation, and are assigned a 10 percent contingency. The remaining half, mostly dealing with electrometallurgical treatment and waste qualifications, is assigned a 20 percent contingency. Appendix D discusses the contingencies in detail.

2.2.7 Summary

The net present value of Alternative 1 is estimated at $604 million. **Table 2–3** presents this total by major cost element and **Table 2–4** presents the costs by site. Appendix F summarizes related details by year for the years 2000 to 2009.

Table 2–3 Cost Summary for Alternative 1 by Cost Element: Electrometallurgical Treatment of Blanket and Driver Spent Nuclear Fuel at ANL-W

Cost Elements	*Net Present Value in Millions of Year-2000 Dollars (including contingencies and escalation)*
Packaging and shipping	
INTEC to ANL-W	6
ANL-W to SRS	Not applicable
ANL-W to INTEC	less than 1
INTEC for a repository (packaging only)	6
SRS for a repository (packaging only)	Not applicable
Sodium cleaning and/or decladding	Not applicable
Treatment and storage	
Equipment at ANL-W	31
Operations at ANL-W	438
Equipment at SRS	Not applicable
Operations at SRS	Not applicable
Waste form qualification at ANL-W	52
Waste form qualification at SRS	Not applicable
Separated plutonium/uranium management	Not applicable
Disposal fees	
High-level radioactive waste	47
Transuranic waste	less than 1
Low-level radioactive waste	less than 1
Deactivation	23
Total	604

Table 2–4 Cost Summary for Alternative 1 by Site: Electrometallurgical Treatment of Blanket and Driver Spent Nuclear Fuel at ANL-W

Site	*Cost in Net Present Value in Millions of Year-2000 Dollars*
INTEC	12
ANL-W	545
SRS	0
Other nonsite-related costs	47
Total	604

2.3 ALTERNATIVE 2: REMOVE SODIUM AND PACKAGE BLANKET SPENT NUCLEAR FUEL IN HIGH-INTEGRITY CANS AND ELECTROMETALLURGICAL TREATMENT OF DRIVER SPENT NUCLEAR FUEL AT ANL-W

2.3.1 Packaging and Shipping

Sodium-bonded spent nuclear fuel currently at INTEC would be shipped to ANL-W at a cost of approximately $6 million. The cost to ship the processed high-level radioactive waste to INTEC for repackaging and repository disposal would be less than $1 million. The cost to package waste canisters at INTEC in 2015 for repository shipping is estimated at about $4 million.

2.3.2 Treatment and Storage

The definition of the electrometallurgical treatment approach in Alternative 2 is similar to that in Alternative 1, except that the driver spent nuclear fuel processing rate would be limited due to the fissile content of the driver fuels and the receipt and handling of shipments from INTEC. Training and transition to limited 24-hour operations (partial crews at night) for treatment steps would take place between October and December 2000. Full processing rates would be achieved around March 2001. The driver spent nuclear fuel processing operations would require increased manpower because cathode processing and casting operations are no longer shared with blanket spent nuclear fuel processing. In addition, sharing of resources would not be optimized because of differences in the blanket cleaning and electrometallurgical treatment processes. Driver spent nuclear fuel processing should be completed by October 2005, with an additional six months required to remove the process fluids from the electrorefiners.

For electrometallurgical treatment waste operations, demonstration-scale equipment will be operated until September 2000. From October 2000 through June 2001, larger-scale ceramic waste equipment (i.e., a hot isostatic press and metal casting furnace) will be installed. From July 2001 through October 2001 waste process qualification runs will be conducted with the full scale equipment. Full capacity waste operations will start in June 2002 and will be completed by October 2007.

To prepare for sodium cleaning and packaging operations in the Hot Fuel Examination Facility, new equipment would have to be designed, built, fabricated, and installed. Operations would take place between June 2003 and October 2008. During the first year of operations, 5 metric tons of blanket spent nuclear fuel would be processed. The remaining 52 metric tons would be completed by October 2008. Filling and sealing each high-integrity can is estimated to require a minimum of two to three hours and a maximum of eight hours, depending on requirements for drawing a vacuum and inerting the can before sealing. Filling and sealing is not a limiting factor in the estimated throughput.

Significant technical support would be required for the driver spent nuclear fuel treatment, blanket spent nuclear fuel cleaning, and electrometallurgical waste processes. The driver spent nuclear fuel treatment processes would be designed to improve throughput and solve problems related to different fuel types. The waste processes and qualification activities would initially emphasize data requirements for the repository license application and full-scale process qualification. The waste technical support is expected to require the present level of effort through October 2002 and gradually would decline to a support level by October 2005. From January 2000 through June 2004, technical support would be needed to finalize the sodium cleaning process. Minimal support would be required for the interfaces with the high integrity can program.

Equipment Costs

Equipment costs for the electrometallurgical treatment of driver spent nuclear fuel only (Alternatives 2 through 5) would total about $30 million, of which about $15 million would be spent during the 2000 to 2002 time period.

Operating Costs

Operating costs for Alternative 2 would be about $36 million in 2000, increasing to $39 million in 2001 and to $45 million in 2006. Afterwards, they would decrease to $33 million in 2007 and $23 to $24 million in 2008 and 2009, then decline rapidly to about $3 million annually through 2015.

2.3.3 Waste Form Qualification

Waste form qualification is estimated to cost $15 million for the high-integrity can and about $47 million for electrometallurgical treatment (two waste forms).

2.3.4 Disposal Fees

Alternative 2 would generate 93 standard disposal canisters of high-level radioactive waste. The repository fee for these canisters in 2015 would be about $44 million. Disposal charges for transuranic waste and low-level radioactive waste would be insignificant.

2.3.5 Deactivation Costs

One year of operating costs at ANL-W would be added following the last full year of processing operations for the deactivation and safe closure of the equipment and materials used for this alternative and for the existing electrometallurgical treatment equipment in the hot cells. After deactivation, a minimal staff would be required to maintain the storage of deactivated waste materials at the Radioactive Scrap and Waste Facility and the Hot Fuel Examination Facility. Deactivation costs, which are included in the operating costs summarized above, would amount to $16 million in 2009.

2.3.6 Contingencies

ANL-W proposes to use a high-temperature vacuum distillation process to clean the sodium. While this method has been used in the past on unirradiated fuel, it has not been used on irradiated fuel and has not been used in recent years. The technical support requirements are significant.

The National Spent Nuclear Fuel Program estimates the cost of high-integrity cans at about $5,200 each in quantities of 1,000, including manufacturing by a company holding an American Society of Mechanical Engineers' Nuclear Certificate of Authorization (commonly known as an N-stamp). Informal discussions with N-stamp-certified metal fabricators within the United States confirmed that this is a reasonable cost estimate (AFI 1999, UST&D 1999).

Important uncertainties in using the high-integrity cans relate to the repository waste acceptance criteria and waste form qualification. For example, the waste acceptance criteria may require ANL-W to draw a vacuum in the high-integrity can; test for leakage; release and redraw the vacuum; fill the high-integrity can with an inert gas; weld the high-integrity can shut; and conduct another leakage test. This type of program, which is similar to the requirements the Nuclear Regulatory Commission imposes on aboveground interim storage casks, would require more time and more technical support than a more modest packaging and sealing requirement. Other waste form uncertainties involve the definition of the reactivity of the residual sodium and the disposal of unconditioned metal fuel. A 60 percent contingency is assigned to the qualification of the high-integrity can waste form. A 40 percent contingency is assigned to the processes and equipment required to clean the blanket spent nuclear fuel for insertion into the high-integrity cans. The direct costs for operations related to cleaning the blanket spent nuclear fuel are estimated at about $60 million, excluding the contingency. Appendix D provides details on contingencies.

2.3.7 Summary

The net present value of Alternative 2 is estimated at $512 million. **Table 2–5** presents this total by major cost element and **Table 2–6** presents the costs by site. Appendix F summarizes related details by year for the years 2000 to 2009.

Table 2–5 Cost Summary for Alternative 2 by Cost Element: Remove Sodium and Package Blanket Spent Nuclear Fuel in High-Integrity Cans and Electrometallurgical Treatment of Driver Spent Nuclear Fuel at ANL-W

Cost Elements	*Net Present Value in Year-2000 Dollars (including contingencies and escalation)*
Packaging and shipping	
INTEC to ANL-W	6
ANL-W to SRS	Not applicable
ANL-W to INTEC	less than 1
INTEC for a repository (packaging only)	4
SRS for a repository (packaging only)	Not applicable
Sodium cleaning and/or decladding	78
Treatment and storage	
Equipment at ANL-W	34
Operations at ANL-W	266
Equipment at SRS	Not applicable
Operations at SRS	Not applicable
Waste form qualification at ANL-W	75
Waste form qualification at SRS	Not applicable
Separated plutonium/uranium management	Not applicable
Disposal fees	
High-level radioactive waste	33
Transuranic waste	less than 1
Low-level radioactive waste	less than 1
Deactivation	16
Total	512

Table 2–6 Cost Summary for Alternative 2 by Site: Remove Sodium and Package Blanket Spent Nuclear Fuel in High-Integrity Cans and Electrometallurgical Treatment of Driver Spent Nuclear Fuel at ANL-W

Site	*Cost in Net Present Value in Millions of Year-2000 Dollars*
INTEC	10
ANL-W	469
SRS	0
Other nonsite-related costs	33
Total	512

2.4 Alternative 3: Declad and Clean Blanket Spent Nuclear Fuel and Electrometallurgical Treatment of Driver Spent Nuclear Fuel at ANL-W; PUREX Process Blanket Spent Nuclear Fuel at SRS

Under this alternative, the driver spent nuclear fuel would be processed using electrometallurgical treatment at ANL-W and the blanket spent nuclear fuel would be declad and cleaned at ANL-W before being shipped to SRS for PUREX processing in F-Canyon. Costs and schedules at SRS in this section are based on data provided by SRS (SRS 1999c). The definition of the electrometallurgical treatment and sodium-cleaning components of Alternative 5 are the same as in Alternative 2.

2.4.1 Packaging and Shipping

Sodium-bonded spent nuclear fuel currently at INTEC would be shipped to ANL-W at a cost of approximately $6 million. The cost to ship the processed high-level radioactive waste to INTEC for repackaging and repository disposal would be less than $1 million. The cost to repackage the high-level radioactive waste at INTEC for shipment to the geologic repository is estimated at about $2 million. Shipping costs to SRS are estimated at $1.3 million. Storage costs at SRS L-Basin would be about $4 million during the 2004 to 2009 shipping and storage period.

2.4.2 Treatment and Storage

Equipment Costs

Equipment costs at ANL-W are estimated at $30 million, as in Alternative 2. Schedules and the timing of expenditures on equipment also would be the same as for Alternative 2.

No equipment costs would be incurred at SRS to prepare for PUREX processing of the declad and cleaned blanket spent nuclear fuel in F-Canyon, to finish the plutonium solutions in FB-Line, or to process the high-level radioactive waste in the Defense Waste Processing Facility. Equipment costs would be incurred at SRS to store the separated plutonium in the New Plutonium Storage Vault (or equivalent), but these costs would be allocable to the complex-wide plutonium immobilization project, and therefore are not included in this cost study. Plutonium immobilization costs are discussed in Section 2.4.4.

Operating Costs

The facilities, staff, and schedules required to declad, clean, and package the blanket spent nuclear fuel in cans for shipment to SRS under Alternative 3 would be similar to those required under Alternative 2.

Operating costs at ANL-W for Alternative 3 would start at about $35 million in 2000, then would average about $38 to $42 million per year through 2006. Operating costs would decline to $33 million in 2007 and

$23 to $24 million from 2008 to 2009, then would decline rapidly to approximately $3 million annually through 2015.

SRS estimates that a campaign to process 57 metric tons of heavy metal of declad and cleaned blanket spent nuclear fuel would take about 20 days of processing over a period of less than six months. The additional time in the campaign is attributable to materials balance and accountability procedures at each end of the campaign, system flush-outs, and downtime for maintenance.

The total cost to maintain and operate F-Canyon would be about $100 million per year. If the facility were in a cold shutdown state, surveillance and maintenance costs would be in the range of $40 million per year. Thus, costs for operations would be around $60 million per year. The cost for processing 57 metric tons of heavy metal of sodium-bonded spent nuclear fuel over six months is estimated at $30 million.

Finishing the 360 kilograms of separated plutonium in the FB-Line is estimated to cost an additional $30 million over a period of six months. As with PUREX processing, most of the time is attributable to materials balances, accountability, system flush-outs, etc. Actual processing time would be in the range of one to two months.

2.4.3 Waste Form Qualification

Since the borosilicate glass waste form would be qualified for disposal in a repository under programs at SRS independent of the sodium-bonded spent nuclear fuel program, there would be no additional cost for waste form qualification under this alternative. Qualification costs for the electrometallurgical treatment waste form are estimated at $47 million.

2.4.4 Disposal Fees

Alternative 3 generates 30 standard disposal canisters at ANL-W for shipment to INTEC for repackaging in 2015. The repository fee for these canisters is about $14 million. Alternative 3 also generates 9 standard disposal canisters at SRS for repository shipment in 2015. The repository fee for these canisters is about $5 million. Low-level radioactive waste disposal costs and transuranic waste disposal costs are estimated at about $1 million each. Costs to store and immobilize the plutonium for disposal are estimated at about $9 million (SRS 1999d).

2.4.5 Deactivation Costs

One year of operating costs at ANL-W would be added following the last full year of processing operations for the deactivation and safe closure of the equipment and materials used for this alternative and for the existing electrometallurgical treatment equipment in the hot cells. After deactivation, a minimal staff would be required to maintain the storage of deactivated waste materials at the Radioactive Scrap and Waste Facility and the Hot Fuel Examination Facility. Deactivation costs, which are included in the operating costs summarized above, would amount to $16 million in 2009.

2.4.6 Contingencies

ANL-W proposes to use a high-temperature vacuum distillation process to clean the sodium. While this method has been used in the past on unirradiated fuel, it has not been used on irradiated fuel and has not been used in recent years. Technical support requirements are significant.

Decladding of irradiated sodium-bonded spent nuclear fuel has been done in the past, but not at ANL-W. A demonstration by Rockwell in 1983 used a laser to cut relatively cold EBR-II blanket spent nuclear fuel. The proposed approach at ANL-W uses mechanical cutting and segmenting.

Currently, F-Canyon's PUREX dissolvers are booked through 2003. Under Alternative 3, ANL-W would ship 22 metric tons of heavy metal of EBR-II and 34 metric tons of heavy metal of Fermi-1 cleaned and declad blanket spent nuclear fuel to SRS from 2004 to 2009. The 22 metric tons of heavy metal of EBR-II blanket spent nuclear fuel would contain about 350 kilograms of plutonium, while the 34 metric tons of heavy metal of Fermi-1 blanket spent nuclear fuel would contain about 7 kilograms of plutonium. Should PUREX processing and plutonium separation in F-Canyon be selected as the preferred method of treatment, the EBR-II blanket spent nuclear fuel would be a higher priority for treatment because it contains more plutonium than the Fermi-1 blanket spent nuclear fuel; therefore, it would be shipped first. EBR-II blanket spent nuclear fuel would be shipped to SRS beginning in 2004 and would continue through 2005. Fermi-1 blanket spent nuclear fuel would be shipped beginning in 2006 and would continue until sometime in 2009. Although the PUREX process in F-Canyon is mature, it may require chemistry modifications to prevent the molybdenum in the Fermi-1 blanket spent nuclear fuel from separating out of solution. These modifications may need to be developed and tested.

Contingencies for cleaning and decladding the blanket spent nuclear fuel are estimated at 40 percent. Contingencies for electrometallurgical treatment operations and waste operations are estimated at 20 percent. Contingencies for production of borosilicate logs at SRS and processing of Fermi-1 blanket spent nuclear fuel at F-Canyon also are estimated at 20 percent. Most other activities at ANL-W and SRS are assigned a 10 percent contingency. Contingencies are discussed in detail in Appendix D.

2.4.7 Summary

The net present value of Alternative 3 is estimated at $545 million. **Table 2–7** presents this total by major cost element and **Table 2–8** presents costs by site. Appendix F summarizes related detail by year for the years 2000 to 2009.

Table 2–7 Cost Summary for Alternative 3 by Cost Element: Declad and Clean Blanket Spent Nuclear Fuel and Electrometallurgical Treatment of Driver Spent Nuclear Fuel at ANL-W; PUREX Process Blanket Spent Nuclear Fuel at SRS

Cost Elements	*Net Present Value in Year-2000 Dollars (including contingencies and escalation)*
Packaging and shipping	
INTEC to ANL-W	6
ANL-W to SRS	1
ANL-W to INTEC	less than 1
INTEC for a repository (packaging only)	2
SRS for a repository (packaging only)	1
Sodium cleaning and/or decladding	78
Treatment and storage	
Equipment at ANL-W	34
Operations at ANL-W	266
Equipment at SRS	Not applicable
Operations at SRS	66
Waste form qualification at ANL-W	52
Waste form qualification at SRS	Not applicable
Separated plutonium/uranium management	8
Disposal fees	
High-level radioactive waste	14
Transuranic waste	1
Low-level radioactive waste	1
Deactivation	16
Total	545

Table 2–8 Cost Summary for Alternative 3 by Site: Declad and Clean Blanket Spent Nuclear Fuel and Electrometallurgical Treatment of Driver Spent Nuclear Fuel at ANL-W; PUREX Process Blanket Spent Nuclear Fuel at SRS

Site	Cost in Net Present Value in Millions of Year-2000 Dollars
INTEC	8
ANL-W	448
SRS	75
Other nonsite-related costs	14
Total	545

2.5 Alternative 4: Melt and Dilute Blanket Spent Nuclear Fuel and Electrometallurgical Treatment of Driver Spent Nuclear Fuel at ANL-W

2.5.1 Packaging and Shipping

Sodium-bonded spent nuclear fuel currently at INTEC would be shipped to ANL-W at a cost of approximately $6 million. The cost to ship the processed high-level radioactive waste to INTEC for repackaging and repository disposal would be less than $1 million. The cost to package waste canisters at INTEC in 2015 for repository shipping is estimated at about $6 million.

2.5.2 Treatment and Storage

Equipment Costs

Equipment costs and schedules for the electrometallurgical treatment portion of the fuel would be the same as for Alternative 2. The lead-time to design, engineer, install, and test a melt and dilute system at ANL-W is estimated at three years from the issuance of the Record of Decision. Equipment costs are estimated at $41 million, of which $20 million would be incurred in 2000 to 2002.

Operating Costs

The definitions of the electrometallurgical treatment and sodium-cleaning components of Alternative 4 are similar to those described in Alternative 2. Staff levels would be slightly reduced because the cleaned blanket spent nuclear fuel would not need to be placed in cans for shipping. The melt and dilute process would require the development, testing, and installation of a new furnace and off-gas system. Technical support and equipment design and fabrication would take place from 2000 through 2005, with continuing support for the first few years of operation. The melt and dilute operations would have an initial one-year period of reduced throughput to verify equipment operations.

Operating costs for Alternative 4 would begin at about $37 million in 2000, then ramp up to $45 million in 2001 and $51 to $55 million for 2002 to 2005. Operating costs then would decline to about $49 million in 2006, $43 million in 2007, $33 million in 2008, $28 million in 2009, and $21 to $24 million in 2010 to 2011, before dropping to $3 million through 2015.

2.5.3 Waste Form Qualification

The waste form qualification costs would be $15 million for the metal ingot generated at ANL-W, and $47 million for the two electrometallurgical treatment waste forms.

2.5.4 Disposal Fees

Alternative 4 would generate waste products requiring 144 standard disposal canisters at INTEC in 2015. The repository fee for these canisters would be about $68 million. The disposal charges for transuranic waste and low-level radioactive waste would be insignificant.

2.5.5 Deactivation Costs

One year of operating costs at ANL-W would be added following the last full year of processing operations for the deactivation and safe closure of the equipment and materials used for this alternative and for the existing electrometallurgical treatment equipment in the hot cells. After deactivation, a minimal staff would be required to maintain the storage of deactivated waste materials at the Radioactive Scrap and Waste Facility and the Hot Fuel Examination Facility. Deactivation costs, which are included in the operating costs summarized above, would amount to $18 million in 2011.

2.5.6 Contingencies

ANL-W proposes to use a high-temperature vacuum distillation process to clean the sodium. While this method has been used in the past on unirradiated fuel, it has not been used on irradiated fuel and has not been used in recent years. Technical support requirements are considered significant.

Alternative 4 would require ANL-W to develop, install, and test a new furnace and off-gas system for the blanket spent nuclear fuel melt and dilute processing. This technology is not well developed. Waste form qualification also is highly uncertain. Contingencies are estimated at 60 percent for activities related to melt and dilute. These activities, including equipment, would represent about $110 million in direct costs. Other contingencies would be equivalent to those for facilities operations and electrometallurgical waste operations, as described in Alternative 2.

2.5.7 Summary

The net present value of Alternative 4 is estimated at $686 million. **Table 2–9** presents this total by major cost element and **Table 2–10** presents costs by site. Appendix F summarizes related detail by year for the years 2000 to 2009.

2.6 Alternative 5: Declad and Clean Blanket Spent Nuclear Fuel and Electrometallurgical Treatment of Driver Spent Nuclear Fuel at ANL-W; Melt and Dilute Blanket Spent Nuclear Fuel at SRS

The definitions of the electrometallurgical treatment and sodium-cleaning components of Alternative 5 are the same as for Alternative 2.

SRS is designing a melt and dilute facility for installation in the process area of Building 105-L. It is expected to begin operations in 2005 and is currently booked through about 2020, assuming single-shift operations. For this cost study, it was assumed that the melt and dilute facility would start processing the blanket spent nuclear fuel in 2022 if capacity becomes available. A full year of preoperational testing is assumed to take place in 2021. Costs and schedules at SRS in this section are based on the SRS Aluminum-Clad Spent Nuclear Fuel Alternative Cost Study and on data SRS provided on the characteristics of the melt and dilute process (DOE 1997b, SRS 1999b).

Table 2–9 Cost Summary for Alternative 4 by Cost Element: Melt and Dilute Blanket Spent Nuclear Fuel and Electrometallurgical Treatment of Driver Spent Nuclear Fuel at ANL-W

Cost Elements	*Net Present Value in Year-2000 Dollars (including contingencies and escalation)*
Packaging and shipping	
INTEC to ANL-W	6
ANL-W to SRS	Not applicable
ANL-W to INTEC	less than 1
INTEC for a repository (packaging only)	6
SRS for a repository (packaging only)	Not applicable
Sodium cleaning and/or decladding	69
Treatment and storage	
Equipment at ANL-W	48
Operations at ANL-W	416
Equipment at SRS	Not applicable
Operations at SRS	Not applicable
Waste form qualification at ANL-W	74
Waste form qualification at SRS	Not applicable
Separated plutonium/uranium management	Not applicable
Disposal fees	
High-level radioactive waste	51
Transuranic waste	less than 1
Low-level radioactive waste	less than 1
Deactivation	15
Total	686

Table 2–10 Cost Summary for Alternative 4 by Site: Melt and Dilute Blanket Spent Nuclear Fuel and Electrometallurgical Treatment of Driver Spent Nuclear Fuel at ANL-W

Site	*Cost in Net Present Value in Millions of Year-2000 Dollars*
INTEC	13
ANL-W	622
SRS	0
Other nonsite-related costs	51
Total	686

2.6.1 Packaging and Shipping

Sodium-bonded spent nuclear fuel currently at INTEC would be shipped to ANL-W at a cost of approximately $6 million. The cost to ship the processed high-level radioactive waste to INTEC for repackaging and repository disposal would be less than $1 million. Shipping costs to SRS are estimated at $1.3 million. Storage costs at SRS L-Basin would be about $4 million, assuming shipments take place from 2004 to 2009, with storage at SRS through the 2022 to 2024 processing period.

2.6.2 Treatment and Storage

Equipment Costs

Equipment costs and schedules at ANL-W would be the same as for Alternative 3.

The proposed melt and dilute facility at SRS would be constructed and operated independent of the Record of Decision issued under the present EIS. However, the SRS facility is not designed for the high-temperature operations and off-gas capture required for sodium-bonded spent nuclear fuel. In 1997, SRS estimated that the equipment costs for its melt and dilute facility would be about $15 million. This cost study assumes an increase of $5 million in the equipment costs for the addition and modification to the facility.

Operating Costs

Operating costs and schedules at ANL-W would be the same as for Alternative 3. Shipments to SRS would be the same as for Alternative 3.

SRS estimates that melt and dilute processing of the cleaned blanket material would be about 100 kilograms of heavy metal per day on a single-shift operation. Allowing for facility downtime and maintenance, the entire 57 metric tons of heavy metal would require about three years of processing time. This processing duration would be shorter than at ANL-W because of the different equipment size and facility layouts at the facilities. The SRS process area hot cell allows for more open space and efficient process flows than the Fuel Conditioning Facility and the Hot Fuel Examination Facility hot cells at ANL-W. The larger furnace at SRS also allows for more rapid processing. This cost study charges one year of full staff operations prior to processing to implement the process and equipment changes needed to convert from melting aluminum-based spent nuclear fuel to melting sodium-bonded spent nuclear fuel.

Single-shift operations are assumed to take place at the facility in 2021 for testing and in 2022 to 2024 for processing, at a cost of $30 million per year.

2.6.3 Waste Form Qualification

The waste form qualification costs would be $15 million for the metal ingots generated at SRS, and $47 million for the two electrometallurgical treatment waste forms at ANL-W.

2.6.4 Disposal Fees

Alternative 5 would generate waste products at ANL-W requiring 30 standard disposal canisters at INTEC in 2015 and 190 disposal canisters at SRS in 2034. The repository fees for the disposal of 190 high-level radioactive waste canisters generated at SRS would be $90 million. The fee for disposal of the 30 canisters generated at ANL-W would be $14 million.

Waste disposal costs for melt and dilute processing at SRS would be higher than for melt and dilute processing at ANL-W, as in Alternative 4, because SRS proposes to create ingots of 30 percent uranium and 70 percent aluminum (SRS 1999b), while ANL-W proposes to create ingots of 50 percent uranium and 50 percent steel. The uranium-aluminum composition would generate more high-level radioactive waste packages than the steel-uranium composition. Disposal charges for transuranic waste and low-level radioactive waste would be insignificant.

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2.6.5 Deactivation Costs

One year of operating costs at ANL-W would be added following the last full year of processing operations for the deactivation and safe closure of the equipment and materials used for this alternative and for the existing electrometallurgical treatment equipment in the hot cells. After deactivation, a minimal staff would be required to maintain the storage of deactivated waste materials at the Radioactive Scrap and Waste Facility and the Hot Fuel Examination Facility. Deactivation costs, which are included in the operating costs summarized above, would amount to $16 million in 2009.

2.6.6 Contingencies

ANL-W proposes to use a high-temperature vacuum distillation process to clean the sodium. While this method has been used in the past on unirradiated fuel, it has not been used on irradiated fuel and has not been used in recent years. Technical support requirements are considered significant.

Decladding of irradiated sodium-bonded spent nuclear fuel has been done in the past, but not at ANL-W. A demonstration by Rockwell in 1983 used a laser to cut relatively cold EBR-II blanket spent nuclear fuel. Prior to this demonstration, Rockwell used mechanical means to declad EBR-II blanket spent nuclear fuel. The proposed approach at ANL-W uses mechanical cutting and segmenting. While the laser approach could be adapted to the ANL-W hot cells, major technical questions exist in areas such as hot cell contamination, remote maintenance, and fiber optic monitoring and focusing.

The melt and dilute project at SRS is scheduled for operation in 2005. However, the SRS off-gas system will not accommodate the high-temperature volatilization and off-gas capture required for the clean and declad blanket spent nuclear fuel. Adding these capabilities will require design, engineering, and installation work beyond that planned by SRS. Waste form qualification also is highly uncertain.

Contingencies at ANL-W are estimated at 40 percent for the blanket spent nuclear fuel cleaning and decladding operations, 20 percent for the electrometallurgical treatment and waste operations, and 10 percent for facilities. Contingencies at SRS for melt and dilute operations, equipment, and waste qualification are estimated at 60 percent. These values are the same as those at ANL-W for Alternative 4.

2.6.7 Summary

The net present value of Alternative 5 is estimated at $686 million. **Table 2–11** presents this total by major cost element and **Table 2–12** presents costs by site. Appendix F summarizes related detail by year for the years 2000 to 2009.

Table 2–11 Cost Summary for Alternative 5 by Cost Element: Declad and Clean Blanket Spent Nuclear Fuel and Electrometallurgical Treatment of Driver Spent Nuclear Fuel at ANL-W; Melt and Dilute Blanket Spent Nuclear Fuel at SRS

Cost Elements	*Net Present Value in Year-2000 Dollars (including contingencies and escalation)*
Packaging and shipping	
INTEC to ANL-W	6
ANL-W to SRS	1
ANL-W to INTEC	less than 1
INTEC to a repository (packaging only)	2
SRS to a repository (packaging only)	7
Sodium cleaning and/or decladding	78
Treatment and storage	
Equipment at ANL-W	34
Operations at ANL-W	266
Equipment at SRS	5
Operations at SRS	137
Waste form qualification at ANL-W	52
Waste form qualification at SRS	16
Separated plutonium/uranium management	Not applicable
Disposal fees	
High-level radioactive waste	66
Transuranic waste	less than 1
Low-level radioactive waste	less than 1
Deactivation	16
Total	686

Table 2–12 Cost Summary for Alternative 5 by Site: Declad and Clean Blanket Spent Nuclear Fuel and Electrometallurgical Treatment of Driver Spent Nuclear Fuel at ANL-W; Melt and Dilute Blanket Spent Nuclear Fuel at SRS

Site	*Cost in Net Present Value in Millions of Year-2000 Dollars*
INTEC	8
ANL-W	447
SRS	165
Other nonsite-related costs	66
Total	686

2.7 ALTERNATIVE 6: MELT AND DILUTE DRIVER AND BLANKET SPENT NUCLEAR FUEL AT ANL-W

2.7.1 Packaging and Shipping

Sodium-bonded spent nuclear fuel currently at INTEC would be shipped to ANL-W at a cost of approximately $6 million. The cost to ship the processed high-level radioactive waste to INTEC for repackaging and repository disposal would be less than $1 million. The cost to package waste canisters at INTEC for repository shipping is estimated at about $9 million.

2.7.2 Treatment and Storage

Melt and dilute processing for highly enriched sodium-bonded spent nuclear fuel is a new concept with a high technical uncertainty. This alternative requires a more complex furnace and off-gas system than Alternative 4 and additional process experimentation to handle the sodium flux in the melted heavy metal. The equipment engineering, technical support, and equipment costs were increased to reflect this additional complexity. Also the throughput rates were reduced because of criticality issues with the driver spent nuclear fuel.

Equipment Costs

Equipment costs are estimated at $46 million, of which about $28 million would be incurred in the 2000 to 2003 period.

Operating Costs

Operating costs would begin at about $35 million in 2000 and then would increase to the $42 to $49 million range through 2007. Operating costs would decline slowly to about $22 million by 2012 to 2013. Operating costs of $12 million and $8 million would be incurred in 2014 and 2015, respectively.

2.7.3 Waste Form Qualification

The waste form qualification costs would be $15 million for each of the two types of metal ingots generated at ANL-W (driver and blanket spent nuclear fuel), and $47 million for the two electrometallurgical treatment waste forms.

2.7.4 Disposal Fees

Alternative 6 would generate waste products requiring 197 standard disposal canisters at INTEC in 2015. The repository fee for these canisters would be about $94 million for the disposal of high-level radioactive waste. Disposal charges for transuranic waste and low-level radioactive waste would be insignificant.

2.7.5 Deactivation Costs

One year of operating costs at ANL-W would be added following the last full year of processing operations for the deactivation and safe closure of the equipment and materials used for this alternative and for the existing electrometallurgical treatment equipment in the hot cells. After deactivation, a minimal staff would be required to maintain the storage of deactivated waste materials at the Radioactive Scrap and Waste Facility and the Hot Fuel Examination Facility. Deactivation costs, which are included in the operating costs summarized above, would amount to $13 million in 2014 to 2015.

2.7.6 Contingencies

ANL-W proposes to use a high-temperature vacuum distillation process to clean the sodium. While this method has been used in the past on unirradiated fuel, it has not been used on irradiated fuel and has not been used in recent years. Technical support requirements are considered significant.

As compared with Alternative 4, this alternative would require a more complex furnace and off-gas system and a significantly different flux to deal with the sodium metal in the driver spent nuclear fuel. Engineering, technical support, and equipment costs would be higher than in Alternative 4 and throughput rates would be lower. Waste form qualification would be highly uncertain.

Contingencies of 60 percent are assigned to melt and dilute activities estimated to have a direct cost of about $150 million, or almost 25 percent of all costs at ANL-W. Facilities costs, representing almost 50 percent of ANL-W costs, are assigned a 10 percent contingency. Sodium removal, with a 40 percent contingency, and electrometallurgical treatment waste operations, with a 20 percent contingency, represent the largest additional cost items.

2.7.7 Summary

The net present value of Alternative 6 is estimated at $753 million. **Table 2–13** presents this total by major cost element and **Table 2–14** presents costs by site. Appendix F summarizes related detail by year for the years 2000 to 2009.

Table 2–13 Cost Summary for Alternative 6 by Cost Element: Melt and Dilute Driver and Blanket Spent Nuclear Fuel at ANL-W

Cost Elements	*Net Present Value in Year-2000 Dollars (including contingencies and escalation)*
Packaging and shipping	
INTEC to ANL-W	6
ANL-W to SRS	Not applicable
ANL-W to INTEC	less than 1
INTEC for a repository (packaging only)	9
SRS for a repository (packaging only)	Not applicable
Sodium cleaning and/or decladding	88
Treatment and storage	
Equipment at ANL-W	56
Operations at ANL-W	440
Equipment at SRS	Not applicable
Operations at SRS	Not applicable
Waste form qualification at ANL-W	74
Waste form qualification at SRS	Not applicable
Separated plutonium/uranium management	Not applicable
Disposal fees	
High-level radioactive waste	69
Transuranic waste	less than 1
Low-level radioactive waste	less than 1
Deactivation	11
Total	753

Table 2–14 Cost Summary for Alternative 6 by Site: Melt and Dilute Driver and Blanket Spent Nuclear Fuel at ANL-W

Site	*Cost in Net Present Value in Millions of Year-2000 Dollars*
INTEC	14
ANL-W	670
SRS	0
Other nonsite-related costs	69
Total	753

3. LIFE CYCLE COSTS SUMMARY

The costs evaluated in this cost study are associated with the six alternatives under the proposed action and a No Action Alternative that involves direct disposal and a deferred decision on the disposal of the spent nuclear fuel. Each alternative, with the exceptions of the No Action Alternative and Alternative 6, involves the electrometallurgical treatment of driver spent nuclear fuel. Differences in costs associated with Alternatives 1 through 6 are related to the methods proposed for treating blanket spent nuclear fuel. Various methods for the treatment and management of spent nuclear fuel are described in more detail in the SBSNF Draft EIS and Appendix A of this cost study. Alternatives for treating and managing sodium-bonded spent nuclear fuel that were evaluated in this cost study include:

- **No Action Alternative**—Direct disposal and a deferred decision on disposal options
- **Alternative 1**—Electrometallurgical treatment of driver and blanket spent nuclear fuel at ANL-W
- **Alternative 2**—Electrometallurgical treatment of driver spent nuclear fuel; sodium removal and package blanket spent nuclear fuel in high-integrity cans at ANL-W
- **Alternative 3**—Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and PUREX process blanket spent nuclear fuel at SRS
- **Alternative 4**—Electrometallurgical treatment of driver spent nuclear fuel and melt and dilute blanket spent nuclear fuel at ANL-W
- **Alternative 5**—Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and melt and dilute blanket spent nuclear fuel at SRS
- **Alternative 6**—Melt and dilute driver and blanket spent nuclear fuel at ANL-W

Table 3–1 presents the total program costs of the No Action Alternative and the six other alternatives as net present values in year-2000 dollars, including contingencies and escalation. The net present value is the amount required to exactly cover program expenditures as they arise over the life of the program.

Table 3–1 Cost Summary (in Millions of Dollars)

Alternative	*Net present value in year-2000 dollars (including contingencies and escalation)*
No Action Alternative: Direct disposal	**443**
Alternative 1: Electrometallurgical treatment of driver and blanket spent nuclear fuel at ANL-W	**604**
Alternative 2: Electrometallurgical treatment of driver spent nuclear fuel with sodium removal and package blanket spent nuclear fuel in high-integrity cans at ANL-W	**512**
Alternative 3: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and PUREX process blanket spent nuclear fuel at SRS	**545**
Alternative 4: Electrometallurgical treatment of driver spent nuclear fuel and melt and dilute blanket spent nuclear fuel at ANL-W	**686**
Alternative 5: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and melt and dilute blanket spent nuclear fuel at SRS	**686**
Alternative 6: Melt and dilute driver and blanket spent nuclear fuel at ANL-W	**753**

Although net present values costs are shown in Table 3–1 to three significant figures, the relative merits of the alternatives should be judged cautiously on the basis of the absolute differences among these figures because:

1. It is uncertain whether each of the alternatives will be able to satisfy waste acceptance criteria.

2. The technical feasibility of the alternatives varies, and although the Table 3–1 costs include contingencies, they do not reflect unquantifiable risks.

3. Some of the cost estimates underlying Table 3–1 are based upon conceptual designs or a partial understanding of the technical requirements for processing the spent nuclear fuel or qualifying the high-level radioactive waste products. These uncertainties are sufficiently large to make it difficult to differentiate between the costs for Alternatives 1 through 3 and Alternatives 4 through 6.

For these reasons, the relative differences in the costs shown in Table 3–1 for the respective alternatives should not be regarded as the sole basis for, or even the dominant factor in, choosing one alternative over another.

For Alternatives 1, 2 and 3, which do not involve melting and diluting the spent nuclear fuel, the net present values of the costs are difficult to distinguish. Uncertainties associated with Alternative 2 include the requirements for filling, inerting, and testing the high-integrity cans, as well as qualification and repository certification of the fuel in the high-integrity cans. Alternative 3 has risks (which are not quantified) concerning the availability of PUREX processing at the SRS F-Canyon. Alternatives 4 and 6, which involve melting and diluting the spent nuclear fuel, have uncertainties associated with the development, installation, and testing of new furnaces and off-gas systems at ANL-W. Alternative 5 has uncertainties associated with the need to redesign the melt and dilute off-gas system at SRS due to higher temperature requirements. All of the alternatives also have some uncertainties over waste form qualification.

Table 3–2 provides a different approach to understanding the costs. It shows the net present values of the costs for each alternative by DOE site (INTEC, ANL-W, and SRS) and by waste disposal costs (high-level radioactive waste, transuranic waste, and low-level radioactive waste).

Table 3–2 Cost by Site and Waste Disposal Charge (Millions of Year-2000 Dollars)

Alternatives	*INTEC*	*ANL-W*	*SRS*	*High-Level Radioactive Waste*	*Transuranic Waste*	*Low-Level Radioactive Waste*	*Total*
No Action Alternative: Direct disposal	16	340	0	87	less than 1	less than 1	443
Alternative 1: Electrometallurgical treatment of driver and blanket spent nuclear fuel at ANL-W	12	545	0	47	less than 1	less than 1	604
Alternative 2: Electrometallurgical treatment of driver spent nuclear fuel with sodium removal and package blanket spent nuclear fuel in high-integrity cans at ANL-W	10	469	0	33	less than 1	less than 1	512
Alternative 3: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and PUREX process blanket spent nuclear fuel at SRS	8	448	75	14	1	1	545
Alternative 4: Electrometallurgical treatment of driver spent nuclear fuel and melt and dilute blanket spent nuclear fuel at ANL-W	13	622	0	51	less than 1	less than 1	686

Alternatives	*INTEC*	*ANL-W*	*SRS*	*High-Level Radioactive Waste*	*Transuranic Waste*	*Low-Level Radioactive Waste*	*Total*
Alternative 5: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and melt and dilute blanket spent nuclear fuel at SRS	8	447	165	66	less than 1	less than 1	686
Alternative 6: Melt and dilute driver and blanket spent nuclear fuel at ANL-W	14	669	0	69	less than 1	less than 1	753

Table 3–2 shows that overall program costs are determined by, and are subject to variation from, the costs for activities at ANL-W and SRS and the disposal of high-level radioactive waste. While costs at INTEC are significant, they do not vary significantly from alternative to alternative. Costs for disposal of transuranic waste (which are charged incrementally) and costs for disposal of low-level radioactive waste are insignificant. Table 3–2 shows that a detailed understanding of the costs and uncertainties associated with operations at ANL-W and SRS and the generation and disposal of high-level radioactive waste is central to understanding the costs for the sodium-bonded spent nuclear fuel program.

A final way of considering the costs of the sodium-bonded spent nuclear fuel program is by annual costs, including contingencies and escalation, in year-2000 dollars. This presentation is similar to that used for annual budgets. **Table 3–3** shows the annual costs for each alternative from 2000 to 2006, which represents the majority of the costs of the program. A final column shows the total expenditure from 2007 to 2035.

Table 3–3 Annual Costs 2000 to 2006 and Beyond
(Thousands of FY 2000 Dollars, Including Contingencies and Escalation)

Alternatives	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007-2035*
No Action Alternative: Direct disposal	44,150	45,599	40,383	36,620	28,582	26,159	18,957	177,330
Alternative 1: Electrometallurgical treatment of driver and blanket spent nuclear fuel at ANL-W	47,115	49,734	50,549	47,457	44,976	43,158	38,729	176,785
Alternative 2: Electrometallurgical treatment of driver spent nuclear fuel with sodium removal and package blanket spent nuclear fuel in high-integrity cans at ANL-W	48,575	56,535	60,402	56,661	53,908	50,090	43,051	60,196
Alternative 3: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and PUREX process blanket spent nuclear fuel at SRS	46,975	53,399	55,792	52,144	49,917	47,825	42,443	49,179
Alternative 4: Electrometallurgical treatment of driver spent nuclear fuel and melt and dilute blanket spent nuclear fuel at ANL-W	49,425	66,168	73,991	69,621	70,989	65,162	57,245	115,062

Alternatives	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007-2035***
Alternative 5: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and melt and dilute blanket spent nuclear fuel at SRS	46,975	53,399	55,792	52,144	49,917	47,825	42,443	252,497
Alternative 6: Melt and dilute driver and blanket spent nuclear fuel at ANL-W	47,180	63,914	66,832	68,854	66,783	60,778	55,536	195,555

An overall conclusion that could be made is that the costs of Alternatives 1, 2, and 3 and Alternatives 4, 5, and 6 are similar, and that differences in preferences related to technical uncertainties, risks, timing of expenditures, potential compliance with the waste form acceptance criteria, and other factors are central to DOE's decision-making process regarding the SBSNF EIS.

APPENDIX A. TECHNICAL AND ECONOMIC EVALUATION OF OPTIONS TO DECLAD AND CLEAN SODIUM-BONDED SPENT NUCLEAR FUEL

The costs associated with the decladding and cleaning of sodium-bonded spent nuclear fuel that are presented in this cost study are based on the melt, drain, evacuate, and calcine (MEDEC) process. ANL-W has used the MEDEC process to recover the uranium from 1,700 unirradiated sodium-bonded fuel pins. In the MEDEC process, the ends of the fuel elements are cut off and the elements are heated. This heating drains off some of the sodium. The residual sodium is extracted by vacuum distillation, condensed, and collected. At the end of a campaign, the sodium is fractionally distilled to isolate the cesium. The cesium-rich stream is stabilized as a high-level ceramic waste, while the sodium stream is stabilized as sodium carbonate and packaged for disposal as low-level or transuranic waste. This process leads to minimal cell contamination and generation of secondary waste. As applied to the present SBSNF Draft EIS, the cladding would not be removed except for processing requirements at SRS in Alternatives 3 and 5.

During the 1980s, Rockwell International removed the cladding and sodium from approximately 17 metric tons of EBR-II very low burnup blanket spent nuclear fuel elements with a laser process (RI 1987). The cladding was cut into strips, which were mechanically separated from the fuel pins. The sodium was removed using an alcohol/water wash. The bare depleted uranium fuel pins were packaged and shipped to SRS for processing in F-Canyon.

Although the Rockwell process was proven in the early 1980s, several important aspects of the process would not be appropriate for the ANL-W hot cell facilities today. These practices include personnel entry into the hot cell, frequent purging of the cell atmosphere, less stringent radiation exposure controls, and minimal waste characterization requirements.

The minimum equipment for the laser process would be a modified class-IV laser, a remotely-operated machine to hold and index the fuel assemblies and elements during cutting operations, a fume hood with remotely changeable filters for contamination control, remotely replaceable fiber optics modules, and assorted remotely-operated equipment to stabilize the mixed waste generated by the alcohol wash. The equipment cost, including required annual refurbishment of the facility's handling equipment during the treatment campaign, is estimated to be on the order of $15 million. A slightly higher amount would be required for engineering design and qualification testing.

The equipment cost for the MEDEC process would be essentially the same if machinery for separating the cladding from the cleaned fuel were included. The main cost component for decladding, cleaning, and high-integrity can packaging would be for the hot cell facility operation, which would be on the order of $13 million annually. With either approach, receiving, handling, and shipping constraints at ANL-W would limit throughput to about 10 metric tons per year, or six years for the sodium-bonded spent nuclear fuel. The laser process would incur some additional cost for disposal of the relatively greater volume and variety of waste generated.

Facility modifications also would be required to implement the laser process. The alcohol wash process is incompatible with the inert atmosphere of the ANL-W hot cells for two reasons: (1) the facilities are operated at a low mositure and oxygen content, and (2) liquid is not allowed in the cell for nuclear criticality control. A new containment room within the hot cell, such as the one currently in the Hot Fuel Examination Facility, would have to be remotely constructed inside the cell. A new modular containment room with internal nontestable high-efficiency particulate air filters, relaxed criticality rules for the moderator (alcohol/water), and direct ventilation to the cell exhaust would cost $5 to 10 million for design, construction, and installation.

Besides the EBR-II and Fermi-1 sodium-bonded spent nuclear fuels, DOE proposes to manage eight elements of 93 percent enriched uranium carbide fuel elements currently at Oak Ridge National Laboratory, 22 test assemblies of sodium-bonded 18 percent enriched uranium oxide fuel stored at INEEL, seven experimental capsules containing a total of 56 kilograms of 93 percent enriched particulate uranium oxide fuel mixed with 39 kilograms of metallic sodium currently at Sandia National Laboratories/New Mexico, and one element at SRS. Depending on burnup history, declad and clean may not be a viable option for any of these fuels. The MEDEC process is preferred for these fuels because it is more effective in removing sodium from small spaces and, in spite of the high fuel enrichment, no moderator limits would be required. The Sandia fuel has no cladding to be removed. For these miscellaneous fuels, the MEDEC process is more appropriate.

Because either option involves new, remotely-operated, and remotely-maintained equipment in an existing hot cell, contingencies would be high. There also is uncertainty about whether the existing hot cell facilities could be remotely modified to accept the process equipment. Although radiation-hardened fiber optics exist, they are not designed to withstand the radiation levels typically found in hot cells containing spent nuclear fuel. The process would have to be designed for routine replacement of these components.

Appendix B. Basis for Operating Costs

B.1 Argonne National Laboratory-West

Operating costs at ANL-W were based on the personnel requirements that historically have been needed to perform operations in the hot cells and analytical chemistry laboratory. Personnel costs were divided into operations, engineering, and technical support, as outlined below. Programmatic personnel costs were based on full-time equivalent (FTE) labor requirements and actual fiscal year 1999 rates. This rate included a portion of the support services and utilities required to keep nuclear facilities and the ANL-W and ANL-E sites operating. Total employee counts would be 1.7 times the number of direct and support FTEs. Equipment costs are listed separately and would include process equipment and equipment required to keep the facilities in operating condition. Costs for major consumables (e.g., chemicals and containers) were directly added. All costs discussed in this section and incorporated in the spreadsheets summarized in Appendix D were based on data provided by ANL (ANL 1999).

- **Operations** — Operations ($150,000 per FTE) covers the costs of shipping, receiving, storing, and treating sodium-bonded spent nuclear fuel and high-level radioactive waste as well as operation of the hot cell facilities, analytical laboratory, and other support facilities. These costs also would include the cost of an additional full year of operations for deactivation activities at the end of the treatment to establish an industrial safe configuration at the end of the work. Cask shipping costs incurred offsite (e.g., casks and trucks) for shipments involving INTEC and SRS were not included.

- **Engineering** — Engineering ($175,000 per FTE) covers the costs to design and engineer treatment process equipment and facility upgrades for the duration of the processing and deactivation activities. This effort was assumed to end a year or two before the end of the proposed action.

- **Technical Support** — Technical support covers the costs for laboratory and engineering-scale work to develop new processes, to qualify proposed waste forms, and to troubleshoot problems. Technical support costs are estimated at $250,000 per FTE for process support involving pilot plants (i.e., gloveboxes) and $200,000 per FTE without pilot plants.

The operations, engineering, and two technical support categories were divided into facility costs and specific processing options. For process operations, the facility category includes the costs to keep the hot cells operational. Examples of these costs include overhead handling maintenance crews, health physics technicians, incidental waste operations, instrumentation technicians, cask-handling crews, additional facility crews, safety analysts, analytical chemistry support, and support staff. Facility costs would be fairly constant except when additional staff are needed for receiving and shipping cask shipments. The processing categories include operating crews, process equipment system engineers, process engineers, analytical chemistry staff for process samples, and support staff. Engineering categories include engineering, analysts and drafting for equipment design, fabrication, and checkout. Technical support estimates were based on typical development costs for new processes (ANL 1999).

B.2 Savannah River Site

Operating costs at SRS were based on incremental costs for the various functions performed at the site. Operating costs at or for the benefit of SRS can be summarized below. Disposal costs are summarized in Section 1.5.4. Contingencies are described in Section 1.5.8.

- **Storage at SRS** — ANL-W proposes to ship the cleaned and declad spent nuclear fuel in 950 canisters. SRS plans to store the aluminum cans in L-Basin prior to either PUREX processing in F-Canyon or melt and dilute processing in Building 105-L. Storage of 950 canisters is estimated to cost about $1 million per year in storage costs at L-Basin (SRS 1999b). Storage costs were prorated based on the number of canisters received and stored at SRS each year. Shipments were assumed to take place from 2004 through 2009. Storage for Alternative 3 was assumed to take place from 2004 through 2009. In Alternative 5, storage was assumed to take place from 2004 to 2024.

- **Processing at SRS** — PUREX processing in Alternative 3 was based on the full cost of operating F-Canyon for a period of six months at $60 million per year (SRS 1999c). The melt and dilute treatment in Alternative 5 was based on the full cost of processing at Building 105-L for a period of four years, including one year of testing and three years of operation, at $30 million per year (DOE 1997b, SRS 1999b). In each case, treatment costs include all operating functions but exclude costs that would be incurred if the process and facility were not operating (e.g., surveillance and maintenance). Thus, full processing costs would be incremental to base facility costs. This costing approach accurately represents the incremental costs at SRS that are attributable to Alternatives 3 and 5, as described in the SBSNF Draft EIS.

  In the case of Alternative 5, the basis for costs presented in this cost study was a 1997 SRS report that evaluated privatization options for a facility that could conduct melt and dilute operations. This cost basis is substantially different from that developed for ANL-W (see Section B.1). In particular, direct costs were lower and operating contingencies were eliminated to reflect private sector construction and operations efficiencies. To make the SRS costs in Alternative 5 consistent with the ANL-W costs, especially those costs associated with Alternatives 4 and 6, this cost study added ANL-W operating contingencies to the SRS costs. This is appropriate since there is no current basis to believe the SRS facility or processing systems envisioned in the 1997 SRS report will be built using the cost structure of the privatized facility described in that study.

B.3 Idaho Nuclear Technology and Engineering Center

Operating costs at INTEC were based on a 1998 life-cycle planning document that includes the packaging and transfer of sodium-bonded spent nuclear fuel at the site. Costs were divided into preparation, packaging, and transfer functions and were itemized in budget-level detail (INEEL 1999a). Costs for repackaging for repository disposal were assumed to reflect firm fixed prices from private vendors (INEEL 1999b).

APPENDIX C. OTHER PROCESSING TECHNOLOGIES

This cost study also evaluated two processing technologies that were considered by DOE but rejected as technically immature: Glass Material Oxidation Dissolution System (GMODS) and Plasma Arc-Vitreous Ceramic Processing (plasma arc).

C.1 GLASS MATERIAL OXIDATION DISSOLUTION SYSTEM

GMODS is a conceptual design for a vitrification technology. Costs and schedules in this section (excluding hot cell costs) are based on data provided by ORNL (ORNL 1999), but are highly speculative.

C.1.1 Equipment and Operating Costs

Equipment Costs

Oak Ridge National Laboratory estimates that development costs for the GMODS technology would be in the range of $15 to 20 million. Development and testing at bench and pilot scale would take at least three years.

Equipment costs for a production scale system suitable for 60 metric tons of heavy metal of sodium-bonded spent nuclear fuel are estimated at $20 to 30 million (excluding research and development and hot cell costs). The largest cost item is the off-gas treatment system. Design, engineering, installation, and testing costs for a production-scale system are estimated to at least equal the $20 to 30 million required for equipment. Research and development for a system designed for shielded and remote operation is estimated to take three years. Design, engineering, and installation of the system in an existing hot cell would probably require an additional three years. Radioactive testing would probably require two years. The system would be available for production-level throughput about eight years after a Record of Decision is issued under the present EIS.

GMODS would require construction of a new hot cell. This cost would be in the $100 million range, but would be partly allocable to the present EIS and partly allocable to general DOE program requirements. DOE has not estimated an allocation basis for the facility since this would involve extensive collaboration with other programs on facilities expansion. This expansion is outside the scope of the present EIS.

Operating Costs

Because GMODS is a conceptual design, operating costs must be based on analogies to other technologies. A 1997 study by SRS comparing various technology options for treating aluminum-based spent nuclear fuel at SRS estimated total labor costs (operations, maintenance, and other direct and area support) for a generalized GMODS at the same level as for the melt and dilute treatment process. Assuming a single-shift operation, this would amount to about $30 million per year over three years, as well as an additional one to two years for startup and testing. Annual operations and maintenance costs were estimated at several million dollars more than for the melt and dilute treatment process.

The estimated three-year period required to process 60 metric tons of heavy metal using GMODS depends on the scale and throughput of the equipment. DOE could elect to develop and install a larger GMODS than would be comparable to the electrometallurgical treatment system in Alternative 1. Equipment costs for this system would be larger than those described above, but operating costs would be lower per unit of material. This cost study assumes that the GMODS would be similar to the electrometallurgical treatment system in scope and size.

C.1.2 Waste Form Packaging and Disposal

The GMODS waste package is a borosilicate glass. Unlike the borosilicate glass logs produced by the Defense Waste Processing Facility, the GMODS glass includes the entire mass of spent nuclear fuel including fissile material, cladding, and structural materials. Thus, the number of waste packages and the allocated fixed costs of high-level radioactive waste disposal are many times higher than for Defense Waste Processing Facility logs.

The GMODS waste form also is a unique waste form for each type of spent nuclear fuel processed (which also is unlike Defense Waste Processing Facility logs). Detailed estimates of the number of waste packages, their mass, their volume, or their qualification requirements were not developed for this cost study. Overall costs would probably be at least $100 million, based on the waste packaging and disposal costs estimated for the other alternatives.

C.2 PLASMA ARC-VITREOUS CERAMIC PROCESS

The plasma arc-vitreous ceramic process uses a very high-temperature electric plasma arc to vaporize materials and convert them into a highly stable ceramic. An idle, bench-scale plasma arc system used to treat nonradioactive material exists at the Transient Reactor Test Facility at ANL-W. In initial tests the plasma arc unit did not perform as expected.

As a practical matter, this system would require extensive modifications to process fuel in a hot cell. The feed, plasma, product removal, and off-gas treatment systems all would change. Also, the system was not designed for remote operation and, more important, remote maintenance. If the Record of Decision under the present EIS were to select plasma arc treatment, DOE would have to design and build a system from the ground up. Costs and schedules in this section (excluding hot cell costs) are based on data provided by SAIC (SAIC 1999a, SAIC 1999b), but are highly speculative.

C.2.1 Equipment and Operating Costs

Equipment Costs

The existing plasma arc system at the Transient Reactor Test Facility cost about $10 million for research and development, $3.5 million for equipment, and $3.5 million for design, engineering, installation, and nonradioactive testing. The costs for a similar system designed for fuel processing in a shielded, remotely operated, and remotely maintained environment, excluding research and development, would be roughly double. Research and development costs likely would be somewhat less than the $10 million spent on the existing system, since the basic approach has been demonstrated in several applications at INEEL or ANL-W (e.g., nonradioactive testing at the Transient Reactor Test Facility and radioactive but nonfuel, nonshielded operations at Pit 9). Overall equipment costs would be in the $20 million range.

Research and development for a system designed for shielded and remote operation is estimated to take two years. Design, engineering, and installation of the system in an existing hot cell would probably require three years. Radioactive testing would probably require an additional two years. The system would be available for production-level throughput about seven years after a Record of Decision is issued under the present EIS.

Plasma arc treatment would require construction of a new hot cell. This cost of would be in the $100 million range but would be partly allocable to the present EIS and partly allocable to general DOE program requirements. DOE has not estimated an allocation basis for the facility since this would involve extensive collaboration with other programs on facilities expansion. This expansion is outside the scope of the present EIS.

Operating Costs

Processing rates were estimated at about 100 kilograms of heavy metal per day, or about the same as the melt and dilute treatment process at SRS. A 1997 study comparing various technology options for treating aluminum-based spent nuclear fuel at SRS estimated total labor costs including operations, maintenance, and other direct and area support for a generalized plasma arc system at the same level as for the melt and dilute treatment process. Assuming a single-shift operation, this would amount to about $30 million per year over three years, as well as at least one to two years for startup and testing. Annual operations and maintenance costs were estimated at several million dollars more than for melt and dilute treatment.

The estimated three-year period required to process 60 metric tons of heavy metal using a plasma arc treatment process depends on the scale and throughput of the equipment. As noted, DOE could elect to develop and install a larger plasma arc system than would be comparable to the electrometallurgical treatment system for the proposed action. Equipment costs for this system would be larger than described above, but operating costs would be lower per unit of material. To maintain consistency with the proposed electrometallurgical treatment system, however, this cost section assumes that the plasma arc treatment system would be similar to the electrometallurgical treatment system in scope and size.

C.2.2 Waste Form Packaging and Disposal

The waste form from the plasma arc treatment process is a ceramic. As with GMODS, the waste form would be unique for each category of spent nuclear fuel since the entire spent nuclear fuel package (heavy metal, cladding, structural material, etc.) would be enclosed in the ceramic. Thus, the number of waste packages would be many times higher than the number of Defense Waste Processing Facility logs. Detailed estimates of the number of waste packages and their mass, volume, or qualification requirements were not developed for this cost study. Overall costs would be at least $100 million, based on the waste packaging and disposal costs estimated for the other alternatives.

Appendix D. Contingencies

This appendix provides an overview of the approach used to estimate the contingencies for each major cost element of the sodium-bonded spent nuclear fuel program.

D.1 Development of Contingencies

Contingencies are percentage increases added to cost estimates to cover additional expenses for unknown events that may occur during the life of the activity. The possibility that a project or program will cost more than its initial estimate is inversely proportional to its maturity. The costs of mature processes or well-designed projects can be accurately estimated, but new technology or projects in the early design stages are difficult to cost accurately. Contingencies are added to the cost estimate to allow for unforseen events that are likely to occur during the project. The contingencies used for each alternative in this cost study are based on a three-step approach that was developed by representatives of ANL-W, INTEC, the National Spent Nuclear Fuel Program, and Science Applications International Corporation in June 1999. The following are steps in this approach:

1. Divide each alternative into four cost categories: (1) base or facilities costs, (2) technical support for the operation, (3) operational equipment costs, and (4) specific equipment costs for the selected alternative.

2. Estimate the direct costs for each major function and each cost category.

3. Estimate a contingency to be added to the cost estimate. The amount of the contingency reflects the maturity and certainty of the project or process.

Contingencies at SRS were made equal to those at ANL-W for similar processes (e.g., melt and dilute) and were based on the technical maturity and certainty of unique processes at SRS (e.g., F-Canyon PUREX). Contingencies at INTEC also were based on technical maturity and certainty. Contingencies were estimated using the approach shown in **Table D–1**. Similar contingencies are used to estimate costs at commercial power plants (EPRI 1989).

Table D–1 Basis for Contingencies

Project/Process Maturity	***Contingency***	***Examples***
Mature	10%	Packaging at INTEC; facilities operation at ANL-W; L-Basin operations at SRS; PUREX at SRS (EBR-II blanket spent nuclear fuel)
Proven but not mature, or mature but with small technical issues, e.g., process modifications	20%	Electrometallurgical treatment operations at ANL-W; electrometallurgical treatment of driver spent nuclear fuel; technical support at ANL-W; PUREX at SRS (Fermi-1 blanket spent nuclear fuel); Defense Waste Processing Facility operations at SRS
Unproven or immature, but with some designs, processes, flow sheets and equipment in place or some related experience base	40%	Blanket spent nuclear fuel cleaning and decladding at ANL-W; high-integrity can operations; and technical support at ANL-W
Unproven and immature with no designs, processes, flow sheets, or equipment in place and no recent experience base	60%	High-integrity can waste qualification at ANL-W; blanket spent nuclear fuel melt and dilute operations; technical support; and waste qualification at ANL-W and SRS.

The contingencies were applied to all activities at ANL-W, SRS, and INTEC except for (1) repackaging operations at INTEC's proposed dry transfer facility, which are assumed to be based on firm fixed prices from a private vendor, and (2) waste disposal fees, which are assumed to already include contingencies comparable to those used in the present cost study.

D.2 Summary of Contingencies by Major Cost Element

Table D–2 shows the contingencies used for each major cost element for each of the alternatives in this cost study. A blank cell in the table for a particular alternative indicates that the cost element does not occur for that alternative. To simplify presentation of the individual contingencies, Table D.2 groups similar elements. The major factors contributing to the contingencies for each alternative are summarized in Section 2 of the cost study.

Contingencies may impact schedules as well as costs. Activities at ANL-W are restricted by the available facilities; thus the schedule must be extended to accommodate the contingency, whereas SRS has sufficient facilities to complete the work scope within the schedule but its costs will increase accordingly.

Table D–2 Contingency Percentages for Major Cost Elements

Activity	*No Action*	*Alt. 1*	*Alt. 2*	*Alt. 3*	*Alt. 4*	*Alt. 5*	*Alt. 6*
Packaging at INTEC for shipment to ANL-W	10	10	10	10	10	10	10
Facilities operation at ANL-W	10	10	10	10	10	10	10
Fuel reconfiguration operations/equipment operations/equipment at ANL-W	40						
Electrometallurgical treatment Waste Operations/ Equipment Operations/Technical Support/ Equipment/Waste Qualification at ANL-W	20	20	20	20	20	20	20
Driver and blanket spent nuclear fuel technical support at ANL-W	40	20					
Blanket spent nuclear fuel clean and high-integrity can operations/equipment operations/ technical support/equipment at ANL-W			40				
High integrity can waste qualification at ANL-W			60				
Driver spent nuclear fuel treatment operations/ equipment operations/technical support/ equipment at ANL-W		20	20	20	20	20	
Blanket spent nuclear fuel clean (and declad in Alternatives 3 and 5) at ANL-W			40	40	40	40	40
Cask rental and shipping for SRS				10		10	
L-Basin Operations at SRS				10		10	
F-Canyon PUREX at SRS				16*			
FB-Line at SRS				10			
Defense Waste Processing Facilty at SRS				20			
Plutonium storage/disposal at SRS				20			
Blanket spent nuclear fuel melt and dilute treatment operations/equipment operations/ technical support/equipment/waste qualification at ANL-W or SRS					60	60	60
Driver spent nuclear fuel melt and dilute treatment operations/sodium removal equipment operations/sodium removal technical support/ sodium removal equipment at ANL-W							40
Driver spent nuclear fuel sodium removal operations at ANL-W							20

Activity	No Action	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6
Repackaging for repository shipping at INTEC **	0	0	0	0	0	0	0
High-level waste disposal **	0	0	0	0	0	0	0
Transuranic waste disposal **	0	0	0	0	0	0	0
Low-level waste disposal **	0	0	0	0	0	0	0

*   Weighted-Average using 20 percent on Fermi-1 blankets and 10 percent on EBR-II blankets.
** No additional contingency; costs already include contingency from DOE or private contractor.

APPENDIX E. WASTE FORM QUALIFICATION

All spent nuclear fuel and high-level waste proposed for disposal in the high-level waste geologic repository must meet the repository's acceptance criteria. DOE has published draft waste acceptance criteria and is currently qualifying waste forms to standards that generally are based on these criteria. In the sodium-bonded spent nuclear fuel program, all but one of the proposed waste forms would incur qualification costs. [Borosilicate logs produced by the SRS Defense Waste Processing Facility will be qualified outside the sodium-bonded spent nuclear fuel program.]

Table E–1 shows the waste forms that would require individual qualification under the sodium-bonded spent nuclear fuel program for each of the alternatives. Except for electrometallurgical treatment waste forms, costs for qualification are estimated at $15 million each, based on a rule-of-thumb used by the National Spent Nuclear Fuel Program. Costs for qualifying electrometallurgical treatment waste forms are estimated at $23.3 million each, based on ongoing work by ANL-W for its Electrometallurgical Treatment Demonstration project. These contingencies are described in Appendix D.

Table E–1 High-level Waste Forms Requiring Qualification and Contingencies

Alternative	*Direct Disposal (HEU and LEU)*	*EMT Metallic Waste*	*EMT Ceramic Waste*	*High-Integrity Cans (LEU)*	*Melt and Dilute Ingot (HEU)*	*Melt and Dilute Ingot (LEU)*
Percent Contingency	40%	20%	20%	60%	60%	60%
No Action Alternative: Direct disposal	x	x	x			
Alternative 1: Electrometallurgical treatment of driver and blanket spent nuclear fuel at ANL-W		x	x			
Alternative 2: Electrometallurgical treatment of driver spent nuclear fuel with sodium removal and package blanket spent nuclear fuel in high-integrity cans at ANL-W		x	x	x		
Alternative 3: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and PUREX process blanket spent nuclear fuel at SRS		x	x			
Alternative 4: Electrometallurgical treatment of driver spent nuclear fuel and melt and dilute blanket spent nuclear fuel at ANL-W		x	x			x

Alternative	***Direct Disposal (HEU and LEU)***	***EMT Metallic Waste***	***EMT Ceramic Waste***	***High-Integrity Cans (LEU)***	***Melt and Dilute Ingot (HEU)***	***Melt and Dilute Ingot (LEU)***
Percent Contingency	40%	20%	20%	60%	60%	60%
Alternative 5: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and melt and dilute blanket spent nuclear fuel at SRS		x	x			x
Alternative 6: Melt and dilute driver and blanket spent nuclear fuel at ANL-W		x	x		x	x

EMT = Electrometallurgical Treatment
HEU = High Enriched Uranium
LEU = Low Enriched Uranium

Table E–1 shows that waste form qualification is required for the two electrometallurgical treatment waste forms in each alternative. This activity is required because each alternative includes either the conversion of the Electrometallurgical Treatment Demonstration Project to full production or the discontinuation of the electrometallurgical treatment demonstration. In either event, the wastes generated by the demonstration program must be qualified for disposal. Overall, waste form qualification represents 5 to10 percent of the total costs for the various alternatives. Alternative 6 has the highest waste form qualification costs because it covers four waste forms and includes two waste forms estimated to have contingencies of 60 percent. Alternatives 1 and 3 have the lowest waste form qualification costs because only the electrometallurgical treatment waste form qualifications would be charged to the program.

APPENDIX F. COST OVER TIME

This appendix discusses costs for the sodium-bonded spent nuclear fuel program in terms of net present value and annual costs. Tables are provided to show undiscounted year-by-year costs at ANL-W for each alternative by major cost group for the 2000 to2009 period. These tables are included to provide insights and additional detail for the basis of the overall costs and decisions.

F.1 Net Present Value

This cost study uses net present values to compare alternatives. The net present value is a single value today that is equal to the sum of the *discounted* values over time. For example, if an alternative has a net present value of $500 million, DOE would be able to cover the expenses over time by setting aside $500 million today. For government projects, the discount rate (or cost of money) that is used to convert a series of costs over time to a single present value is specified by the Office of Management and Budget. The rate used in this cost study is 4.9 percent per year (including inflation) (OMB 1999). This compares to an escalation rate of 2.8 percent per year (including inflation) (INEEL 1999a).

The net present value is a useful figure for identifying the least costly alternative or alternatives in a program. It also is useful to separately consider the timing of the expenditures for each alternative. Alternatives may have similar net present values but different cost profiles. Depending on one's decision criteria, the cost profile over time may have more significance than the net present value today. **Table F–1** shows the net present value of the life-cycle costs for each alternative.

Table F–1 Net Present Values of the Alternatives (Millions of Year-2000 Dollars)

Alternative	*Total*
No Action Alternative: Direct disposal	443
Alternative 1: Electrometallurgical treatment of driver and blanket spent nuclear fuel at ANL-W	604
Alternative 2: Electrometallurgical treatment of driver spent nuclear fuel with sodium removal and package blanket spent nuclear fuel in high-integrity cans at ANL-W	512
Alternative 3: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and PUREX process blanket spent nuclear fuel at SRS	545
Alternative 4: Electrometallurgical treatment of driver spent nuclear fuel and melt and dilute blanket spent nuclear fuel at ANL-W	686
Alternative 5: Electrometallurgical treatment of driver spent nuclear fuel; declad and clean blanket spent nuclear fuel at ANL-W and melt and dilute blanket spent nuclear fuel at SRS	686
Alternative 6: Melt and dilute driver and blanket spent nuclear fuel at ANL-W	753

F.2 Summary Year-by-Year Costs

Table F–2 presents the year-by-year costs for the ten-year period 2000 to 2009, including contingencies *without discounting*. This presentation is useful for identifying the alternatives that would impose the greatest budgetary impact on the government over the next 10 years.

Table F–2 illustrates annual funding issues that cannot be seen in the net present value summaries in Table F–1:

- On a net present value basis, Alternatives 1, 2, and 3 would be of roughly equal cost, with Alternative 2 being the least and Alternative 1 being the most costly. A decision criterion that favored lowest costs would prefer Alternative 2 over Alternatives 1 and 3. This changes when annual expenditures are considered, as in Table F–2. Table F–2 shows that Alternative 2 would have higher annual expenditures for FY 2000 through FY 2006. A decision that favored low early year costs would select Alternative 1 over Alternatives 2 and 3.

- Alternative 3 would have the highest single-year cost, at more than $130 million in 2009. This cost would reflect the high annual cost but brief duration at F-Canyon and the FB-Line. A decision criterion that favors level spending over time would downgrade Alternative 3 on this basis.

- On a net present value basis, Alternatives 4 through 6 would be of roughly equal costs. In terms of yearly budgets, however, Alternative 5 would have much lower costs over the first 10 years of the program. This is reasonable, since major processing activities in Alternative 5 at SRS would be deferred for about 20 years. A decision criterion that favors deferred spending would upgrade Alternative 5.

A comparison of Tables F–1 and F–2 shows how different decision criteria (e.g., lowest net present value versus lowest costs for 10 years) could result in different preferences among apparently similar alternatives. It also suggests that because the costs would be similar for Alternatives 1 through 3 and for Alternatives 4 through 6, extra weight should be placed on the technical certainty associated with each alternative.

F.3 Year-by-Year Costs by Alternative

Table F–2 shows that undiscounted annual costs would begin in the range of $45 to $50 million regardless of the alternative and then would increase as a function of escalation (2.8 percent per year) and factors unique to each of the alternatives. Annual costs would begin in the $45 to $50 million range because this would represent the full cost of operating the ANL-W facilities, which would be required for any of the alternatives, and the costs for new equipment. Since essentially the same ANL-W facilities and staff would be used at similar levels in the first few years of each alternative, costs would begin at similar levels. Costs at INTEC at the beginning of the program would be the same for each alternative. Costs at SRS would not be incurred in the first few years of the program. Thus, all variations in costs in the early years of the program would be attributable to activities at ANL-W. **Tables F–3 through F–9** show undiscounted annual costs at ANL-W grouped by major cost element for the 2000 to 2009 period.

Table F–2 Annual Costs
(current dollars, including contingencies and escalation)

Alternatives	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
No Action (Direct Disposal)	44,150	47,833	44,438	42,271	34,609	33,228	25,259	12,311	12,282	12,626
Alternative 1 (Electrometallurgical Treatment)	47,115	52,171	55,624	54,780	54,460	54,820	51,605	50,599	51,641	53,087
Alternative 2 (Electrometallurgical Treatment/High-Integrity Cans)	48,575	59,305	66,466	65,405	65,277	63,626	57,364	50,368	35,627	33,717
Alternative 3 (Electrometallurgical Treatment/PUREX at SRS)	46,975	56,016	61,394	60,191	60,444	60,747	56,553	51,743	37,314	130,699
Alternative 4 (Electrometallurgical Treatment/Melt and Dilute at ANL-W)	49,425	69,411	81,420	80,365	85,960	82,770	76,277	69,119	55,159	47,654
Alternative 5 (Electrometallurigcal Treatment/Melt and Dilute at SRS)	46,975	56,016	61,394	60,191	60,444	60,747	56,553	51,743	37,314	35,322
Alternative 6 (Melt and Dilute at ANL-W)	47,180	67,046	73,542	79,479	80,867	77,201	73,999	67,979	61,407	56,972

Table F–3 Direct Disposal Option of the No Action Alternative, Annual Costs by Major Cost Group
(current dollars, including contingencies and escalation)

Major Cost Group	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Operating Costs	39,130	42,117	40,633	40,370	32,655	32,022	24,138	11,280	11,596	11,921
Sodium Cleaning/Decladding										
Other Operations	17,975	19,589	21,976	22,591	16,389	16,848	7,128	4,271	4,390	4,513
Equipment	7,315	7,520	4,623	4,525	4,651	3,235	682	701	720	740
Waste Qualification	13,840	15,009	14,034	13,254	11,615	11,940	6,137	6,309	6,486	6,667
Other Technical Support										
Deactivation	0	0	0	0	0	0	10,191	0	0	0
Equipment	4,520	4,893	2,536	598	614	631	649	667	686	705
Total at ANL-W (undiscounted)	43,650	47,010	43,170	40,967	33,269	32,654	24,787	11,948	12,282	12,626

Table F–4 Alternative 1, Annual Costs by Major Cost Group (current dollars, including contingencies and escalation)

Major Cost Group	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Operating Costs	42,015	46,445	49,822	49,729	49,267	51,663	49,185	48,233	49,583	50,972
Sodium Cleaning/Decladding										
Other Operations	17,900	25,972	32,549	36,394	39,138	41,250	43,502	42,391	43,578	44,798
Equipment	7,315	7,520	6,621	5,513	4,769	4,902	2,850	2,930	3,012	3,096
Waste Qualification	11,040	9,252	8,116	7,170	5,361	5,511	2,833	2,912	2,993	3,077
Other Technical Support	5,760	3,701	2,536	652	0	0	0	0	0	0
Deactivation	0	0	0	0	0	0	0	0	0	0
Equipment	4,600	4,904	4,534	3,748	3,853	2,583	1,947	2,002	2,058	2,116
Total at ANL-W (undiscounted)	46,615	51,349	54,356	53,477	53,120	54,246	51,133	50,235	51,641	53,087

Table F–5 Alternative 2, Annual Costs by Major Cost Group (current dollars, including contingencies and escalation)

Major Cost Group	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Operating Costs	43,375	51,441	58,340	59,941	59,994	59,688	54,945	48,002	34,941	33,012
Sodium Cleaning/Decladding & High-Integrity Cans	6,300	10,218	12,132	12,624	11,414	11,171	11,483	10,106	8,556	0
Other Operations	17,000	22,888	27,730	30,788	34,263	35,636	36,634	33,583	21,951	4,513
Equipment	5,635	5,793	5,289	4,145	3,596	3,697	2,107	1,401	1,441	740
Waste Qualification	12,640	12,542	13,189	12,385	10,721	9,185	4,721	2,912	2,993	3,077
Other Technical Support	1,800	0	0	0	0	0	0	0	0	0
Deactivation	0	0	0	0	0	0	0	0	0	24,681
Equipment	4,700	7,042	6,859	4,161	3,942	3,364	1,947	2,002	686	705
Total Costs at ANL-W (undiscounted)	48,075	58,483	65,198	64,101	63,936	63,052	56,892	50,004	35,627	33,717

Table F–6 Alternative 3, Annual Costs by Major Cost Group (current dollars, including contingencies and escalation)

Major Cost Group	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Operating Costs	41,775	48,152	53,267	54,726	54,633	56,014	53,056	48,002	34,941	33,012
Sodium Cleaning/Decladding	6,300	10,218	12,132	12,624	11,414	11,171	11,483	10,106	8,556	0
Other Operations	17,000	22,888	27,730	30,788	34,263	35,636	36,634	33,583	21,951	4,513
Equipment	5,635	5,793	5,289	4,145	3,596	3,697	2,107	1,401	1,441	740
Waste Qualification	11,040	9,252	8,116	7,170	5,361	5,511	2,833	2,912	2,993	3,077
Other Technical Support	1,800	0	0	0	0	0	0	0	0	0
Deactivation	0	0	0	0	0	0	0	0	0	24,681
Equipment	4,700	7,042	6,859	4,161	3,942	3,364	1,947	2,002	686	705
Cask Rental and Shipping to SRS	0	0	0	0	283	290	299	307	316	195
Total Costs at ANL-W (undiscounted)	46,475	55,193	60,126	58,887	58,858	59,668	55,302	50,311	35,943	33,912

Table F–7 Alternative 4, Annual Costs by Major Cost Group (current dollars, including contingencies and escalation)

Major Cost Group	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Operating Costs	44,175	58,175	68,094	71,293	79,650	78,774	73,810	66,717	53,101	45,539
Sodium Cleaning/Decladding	6,300	9,715	11,318	9,810	9,537	8,398	8,633	7,176	6,461	6,642
Other Operations	17,000	22,888	27,899	32,526	41,232	45,004	46,264	43,483	32,129	33,028
Equipment	5,635	8,096	10,615	9,620	9,225	8,840	4,750	3,440	3,536	740
Waste Qualification	11,040	9,252	8,116	8,908	8,934	11,021	8,498	8,735	6,984	5,129
Other Technical Support	4,200	8,224	10,145	10,429	10,721	5,511	5,665	3,882	3,991	0
Deactivation	0	0	0	0	0	0	0	0	0	0
Equipment	4,700	10,331	11,931	7,637	4,836	3,364	1,947	2,002	2,058	2,116
Total at ANL-W (undiscounted)	48,875	68,506	80,025	78,930	84,485	82,138	75,758	68,719	55,159	47,654

Table F–8 Alternative 5, Annual Costs by Major Cost Group (current dollars, including contingencies and escalation)

Major Cost Group	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Operating Costs	41,775	48,152	53,267	54,726	54,633	56,014	53,056	48,002	34,941	33,012
Sodium Cleaning/Decladding	6,300	10,218	12,132	12,624	11,414	11,171	11,483	10,106	8,556	0
Other Operations	17,000	22,888	27,730	30,788	34,263	35,636	36,634	33,583	21,951	4,513
Equipment	5,635	5,793	5,289	4,145	3,596	3,697	2,107	1,401	1,441	740
Waste Qualification	11,040	9,252	8,116	7,170	5,361	5,511	2,833	2,912	2,993	3,077
Other Technical Support	1,800	0	0	0	0	0	0	0	0	0
Deactivation	0	0	0	0	0	0	0	0	0	24,681
Equipment	4,700	7,042	6,859	4,161	3,942	3,364	1,947	2,002	686	705
Cask Rental and Shipping to SRS					283	290	299	307	316	195
Total at ANL-W (undiscounted)	46,475	55,193	60,126	58,887	58,858	59,668	55,302	50,311	35,943	33,912

Table F–9 Alternative 6, Annual Costs by Major Cost Group (current dollars, including contingencies and escalation)

Major Cost Group	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Operating Costs	42,340	54,618	59,032	67,062	72,904	71,427	70,635	65,613	59,349	54,857
Sodium Cleaning/Decladding	6,180	11,195	11,297	13,178	11,123	10,028	10,309	7,880	7,184	7,385
Other Operations	15,945	17,502	17,611	23,417	31,114	33,914	35,359	37,696	36,955	37,990
Equipment	4,375	6,800	10,172	9,392	9,225	8,197	7,972	5,478	4,234	4,353
Waste Qualification	11,040	9,252	8,116	8,908	8,934	11,021	8,498	8,735	6,984	5,129
Other Technical Support	4,800	9,869	11,836	12,167	12,508	8,266	8,498	5,824	3,991	0
Deactivation	0	0	0	0	0	0	0	0	0	0
Equipment	4,340	11,606	13,242	11,114	6,623	5,201	2,892	2,002	2,058	2,116
Total at ANL-W (undiscounted)	46,680	66,224	72,273	78,175	79,527	76,627	73,527	67,615	61,407	56,972

GLOSSARY

***Blanket Fuel* —** Those fuel tubes or elements composed of depleted or natural enrichment of uranium, placed at the perimeter of the reactor core, and used to breed the fissile material plutonium-239 or used as shielding.

***Calcine* —** To heat to a high temperature without fusing in order to decompose or oxidize; the material produced by converting high-level radioactive waste to unconsolidated granules or powder.

***Canister* —** The structure surrounding the waste form (e.g., high-level radioactive waste immobilized in borosilicate glass) that facilitates handling, storage, transportation, and/or disposal. A canister is a metal receptacle with the following purpose: (1) for solidified high-level radioactive waste, its purpose is a pour mold and (2) for spent nuclear fuel, it may provide structural support for intact spent nuclear fuel, loose rods, nonfuel components, or confinement of radionuclides.

***Canning* —** The process of placing spent nuclear fuel in canisters to retard corrosion, contain radioactive releases, or control geometry.

***Cask* —** A heavily shielded container that meets U.S. Nuclear Regulatory Commission and U.S. Department of Transportation regulatory requirements and is used to store and/or ship radioactive materials (i.e., spent nuclear fuel or high-level radioactive waste). Lead, depleted uranium, and steel are common materials used in the manufacture of casks.

***Characterization* —** The determination of waste composition and properties, whether by review of process knowledge, nondestructive examination or assay, or sampling and analysis, generally done for the purpose of determining appropriate storage, treatment, handling, transport, and disposal requirements.

***Cladding* —** The outer jacket of fuel elements usually made of aluminum, stainless steel, or zirconium alloy, used to prevent fuel corrosion and retain fission products during reactor operation, or to prevent releases into the environment during storage.

***Conditioning* —** Any process which prepares or treats spent nuclear fuel or high-level radioactive waste for storage, transportation, or disposal in accordance with regulatory requirements.

***Container* —** With regard to radioactive wastes, the metal envelope in the waste package that provides the primary containment function of the waste package and is designed to meet the containment requirements of 10 CFR 60.

Constant Dollars — Dollars from different years that have been made equivalent by discounting to a common date. The cost study discounts all current-year dollars (including contingencies and escalation) to constant dollars expressed in terms of the year 2000. Constant dollar analysis is used to compare costs that take place over different periods of time.

Current-Year Dollars — Dollars from different years that have not been discounted to constant dollars.

Contingencies — Costs that are expected to occur, but cannot be directly estimated or attached to a specific line-item or time period. Contingencies are developed by analogies to cost-estimating experience for similar types of projects and processes and similar levels of technical maturity.

Decladding — The process of mechanically removing the cladding from the fuel pin in a fuel element.

Decommissioning — The process of removing a facility from operation, followed by decontamination, entombment, dismantlement, or conversion to another use.

Decontamination — The actions taken to reduce or remove substances that pose a substantial present or potential hazard to human health or the environment, such as radioactive or chemical contamination from facilities, equipment, or soils by washing, heating, chemical or electrochemical action, mechanical cleaning, or other techniques.

Depleted Uranium — Uranium with a smaller percentage of uranium-235 than the 0.711 weight percent found in natural uranium. It is a byproduct of the uranium enrichment process, during which uranium-235 is collected from one batch of uranium, thereby depleting it, and adding to another batch to increase its concentration of uranium-235.

Dilute — To reduce the concentration of a substance by adding it to another material.

Discounting and Discount Rate — Discounting converts dollars that are generated or expended at different times to a common time, the year 2000 in the cost study. The rate that relates these dollars over time is the discount rate, or the cost of money. The result is expressed in constant dollars, i.e., year-2000 dollars. The Office of Management and Budget annually specifies the discount rate for use in projects like the SBSNF EIS. For 1999, a nominal discount rate of 4.9 percent per year is used.

Disposal — The isolation of radioactive wastes from the accessible environment, as defined in 10 CFR 60.2. Disposal means the emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste.

Driver Fuel — These fuel tubes or assemblies usually contain enriched uranium, plutonium, or thorium materials, which can be fissioned (or split) by neutrons. Because this fuel drives neutron bombardment of targets or blanket in a production, breeder, or research reactor, these fuels are called drivers.

Electrometallurgical Treatment — A technique to collect, concentrate, and immobilize fission products and transuranic elements from metallic spent nuclear fuel by removing the uranium in the spent fuel with an electrochemical cell. The treatment alters the chemical and physical nature of spent nuclear fuel to reduce its toxicity, volume, and mobility to render it amendable to transport, storage, or disposal.

Enriched Uranium — Uranium in which the abundance of the isotope uranium-235 is increased above the normal (naturally occurring) level of 0.711 weight percent.

Environmental Impact Statement (EIS) — A document required of Federal agencies by the National Environmental Policy Act for major proposals or legislation significantly affecting the environment. A tool for decision making, it describes the positive and negative effects of the undertaking and alternative actions.

Escalation — An increase in the price level of a particular item over time. If inflation is included, the escalation rate is nominal. If it is excluded, the escalation rate is real. The cost study use nominal escalation.

Fuel Assembly — A cluster of fuel elements (or rods).

Fuel Element — Nuclear reactor component that includes the fissile material (fuel pin) sealed in cladding.

Fuel Pin — The uranium metal or alloy that undergoes fission in a nuclear reactor.

***Geologic Repository* —** A system that is intended to be used for, or may be used for, the disposal of radioactive waste or spent nuclear fuel in excavated geologic media. A geologic repository includes (a) the geologic repository operations area, and (b) the portion of the geologic setting that provides isolation. A near-surface disposal area is not a geologic repository.

***Heavy Metals* —** Metallic or semimetallic elements of high molecular weight, such as mercury, chromium, cadmium, lead, and arsenic, that are toxic to plants and animals at known concentrations.

***High-Level Radioactive Waste* —** The highly radioactive waste material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid waste derived from such liquid waste that contains fission products in sufficient concentrations; and other highly radioactive material that is determined, consistent with existing law, to require permanent isolation.

***Ingot* —** A mass of metal cast in a standard shape for convenient storage or shipment.

***Hot Cell/Hot Cell Facility* —** A heavily shielded enclosure for handling and processing (by remote means or automatically), or storing highly radioactive materials.

Inflation — An increase in the overall level of prices in the economy. If prices over time include inflation and real escalation, then the nominal discount rate is used for discounting. If prices over time exclude inflation, then the real discount rate is used for discounting. The cost study uses nominal prices and discount rates. Discounting removes the effects of inflation but not escalation.

Life-Cycle Costs — Costs associated with managing the sodium-bonded spent nuclear fuel from its current configuration through ultimate disposition of the spent fuel and associated wastes.

***Low-Level Radioactive Waste* —** Waste that contains radioactivity, but is not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or by-product material as defined by Section 11e (2) of the Atomic Energy Act of 1954, as amended.

***Management* —** As used in this cost report, the stabilization and interim storage of sodium-bonded spent nuclear fuel pending final disposition.

***Metric Tons of Heavy Metal (MTHM)* —** Quantities of unirradiated and spent nuclear fuel are traditionally expressed in terms of metric tons of heavy metal (typically uranium), without the inclusion of other materials, such as cladding, alloy materials, and structural materials. A metric ton is 1,000 kilograms, which is equal to about 2,200 pounds.

Net Present Value — A single value today equal to the sum of discounted values over time. For example, if an alternative has a net present value of $500 million, DOE would be able to exactly cover the expenses over time by setting aside $500 million today. Net present values vary based upon the rates of escalation and discount and the timing of expenditures.

Nominal — A price level or rate (e.g., a discount rate) that includes inflation. A nominal rate of escalation of 2.8 percent per year is used in the cost study.

***Nuclear Regulatory Commission (NRC)* —** The Federal agency that regulates the civilian nuclear power industry in the United States.

***Off-gas* —** Volatile and semi-volatile gaseous products that are released during a process.

Off Site **—** As used in the environmental impact statement, the term denotes a location, facility, or activity occurring outside of the boundary of the facility of interest.

Particulate Matter **—** Air pollutants including dust, dirt, soot, smoke, or liquid droplets emitted into the air. "Total suspended particulate" was first used as the indicator for particulate concentrations. Current standards use the indicators "PM_{10}" and "$PM_{2.5}$," which include only those particles with an aerodynamic diameter smaller than or equal to 10 micrometers and 2.5 micrometers, respectively. The smaller particles are more responsible for adverse health effects because they reach further into the respiratory tract.

Plutonium **—** A heavy, radioactive, metallic element with the atomic number 94. It is produced artificially in a reactor by bombardment of uranium with neutrons and is used in the production of nuclear weapons.

PUREX (Plutonium-Uranium Extraction) **—** A chemical separation process that has been used for recovering uranium and plutonium from irradiated fuel in a form usable as reactor fuel or for weapons. The process uses aqueous solvent extraction to perform the separation. This technology can also be used to treat spent nuclear fuel for disposal.

Radioactive Waste **—** Materials from nuclear operations that are radioactive or are contaminated with radioactive materials, and for which use, reuse, or recovery are impractical.

Radioactivity **—** The spontaneous decay or disintegration of unstable atomic nuclei, accompanied by the emission of radiation.

Real — A price level or rate (e.g., a discount rate) that excludes inflation.

Record of Decision **—** A document prepared in accordance with the requirements of the Council on Environmental Quality and National Environmental Policy Act regulations 40 CFR 1505.2, that provides a concise public record of the decision on a proposed Federal action for which an environmental impact statement was prepared. A Record of Decision identifies the alternatives considered in reaching the decision, the environmentally preferable alternative(s), factors balanced in making the decision, whether all practicable means to avoid or minimize environmental harm have been adopted, and if not, why they were not.

Reprocessing (of spent nuclear fuel) **—** Processing of reactor-irradiated nuclear material (primarily spent nuclear fuel) to recover fissile and fertile material, in order to recycle such materials primarily for defense programs. Historically, reprocessing has involved aqueous chemical separations of elements (typically uranium or plutonium) from undesired elements in the fuel.

Risk **—** A quantitative or qualitative expression of possible loss that considers both the probability that a hazard will cause harm and the consequences of that event.

Scope **—** In a document prepared pursuant to the National Environmental Policy Act of 1969, the range of actions, alternatives, and impacts to be considered.

Shutdown **—** For a U.S. Department of Energy (DOE) reactor, that condition in which the reactor has ceased operation and DOE has declared officially that it does not intend to operate it further (see DOE Order 5480.6, *Safety of Department of Energy-Owned Nuclear Reactors*).

Sodium-bonded **—** Physically in contact with and attached to the element sodium.

Spent Nuclear Fuel **—** Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated for reprocessing.

Standard Canister **—** As used in this cost report, this refers to a standardized DOE canister which is a stainless steel, right circular cylinder with a nominal outside diameter of 45.7 centimeters (18 inches), a nominal thickness of .59 centimeters (.375 inches) and a maximum overall length of 3 meters (118.11 inches) with a usable length of 2.55 meters (100.28 inches). The standard canister is used for storing spent nuclear fuel assemblies, high-integrity cans, and any other waste packages.

Transuranic Waste **—** Waste contaminated with alpha-emitting radionuclides with half-lives greater than 20 years and concentrations greater than 100 nanocuries/gram at time of assay. It is not a mixed waste. (A nanocurie is 10^{-9} curies.)

Treatment **—** As used in this cost report, a process to remove and/or stabilize metallic sodium.

Uranium **—** A heavy, silvery-white metallic element (atomic number 92) with several radioactive isotopes that is used as fuel in nuclear reactors or as radiation shielding.

Vitreous **—** Resembling or having the nature of glass.

Vitrification **—** The process of immobilizing waste material that results in glass-like solid.

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